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REPORT OF THE SPECIAL COMMITTEE FOR THE LAKE SUPERIOR REGION

TO C. WILLARD HAYES, ROBERT BELL, FRANK D. ADAMS, AND CHARLES R. VAN HISE, GENERAL COMMITTEE ON THE RELATIONS OF THE CANADIAN AND THE UNITED STATES GEOLOGICAL SURVEYS

INTRODUCTORY NOTE BY C. R. VAN HISE

The report below of the special committee on the nomenclature and correlation of the geological formations of the United States and Canada is the first joint report of the geologists of the two countries. Before the death of Dr. G. M. Dawson, formerly director of the Canadian Geological Survey, I had correspondence with him in reference to joint field-work in the Lake Superior region. It was agreed between us that such field-work should be undertaken, but his untimely death occurred before anything was done.

After Dr. Dawson's death I continued correspondence upon the subject with Dr. Robert Bell, acting director of the Canadian Geological Survey. As a result of this correspondence, December 22, 1902, Dr. Bell wrote to Dr. C. D. Walcott, director of the United States Geological Survey, suggesting a conference in reference to the mutual interest of the two Surveys. This letter led to the appointment of a committee—consisting of C. W. Hayes and C. R. Van Hise, for the United States Geological Survey, and Robert Bell and Frank D. Adams, for the Canadian Geological Survey—to consider all questions as to the successions of formations, and as to nomenclature, which concerned the two Surveys.

This committee, with C. W. Hayes as chairman, met for the first time at Washington, January 2, 1903. At this meeting several special committees were appointed to consider different districts along the international boundary. For the Lake Superior region the following committee was appointed: for the United States, C. R. Van Hise and C. K. Leith, of the United States Geological Survey, and A. C. Lane, state geologist of Michigan; and for Canada, Robert Bell and Frank D. Adams, of the Canadian Geological Survey, and W. G. Miller, provincial geologist of Ontario.

August 3, 1904, this special committee met in the Marquette district of Michigan, and during the six weeks following visited successively the Gogebic, Mesabi, Vermilion, Rainy Lake, Lake of the Woods, Animikie, and original Huronian districts. After finishing the field-work, a report in preliminary form was drawn up.

In December, 1904, another meeting of the special committee was held at Philadelphia, further to consider the report, all members of the committee being present except C. R. Van Hise. At this meeting the report of the subcommittee was completed as given below.

REPORT OF THE COMMITTEE

Your special committee on the Lake Superior region, during the months of August and September, 1904, visited various districts in the Lake Superior country, their purpose being to ascertain, if possible, whether they could agree upon the succession and relations of the formations in the various districts, and could further agree upon a nomenclature appropriate to express the facts. The districts visited were the Marquette, the Penokee-Gogebic, the Mesabi, the Vermilion, the Rainy Lake, the Lake of the Woods, the Thunder Bay, and the original Huronian of the north shore of Lake Huron. Aside from the regular members of the special committee, for parts of the trip other geologists were with the party. Dr. C. W. Hayes, geologist in charge of geology, United States Geological Survey, and a member of the general committee, was with the party for the Marquette, Penokee-Gogebic, Mesabi, Vermilion, and Rainy Lake districts. Professor A. E. Seaman was with the party for the Marquette,

Penokee-Gogebic, Rainy Lake, Lake of the Woods, and Thunder Bay districts. Mr. J. U. Sebenius was with the party for the Mesabi district, Mr. W. N. Merriam, for the Mesabi and Vermilion districts; Mr. W. N. Smith, for the Thunder Bay district; Mr. E. D. Ingall and Mr. T. D. Denis, for the Lake Huron district. The knowledge of these men was of great assistance to the committee.

In the following pages we shall give the successions and relations of formations which we believe to obtain for each of the districts visited, and give our opinion as to the major correlation of the rock series of the various districts, so far as this can be safely done, and the nomenclature which seems to best express the facts.

For each district, unless otherwise specified, the succession will be considered in descending order. In giving the successions for the various districts, we shall use, for convenience, the names suggested by geologists who have done the detailed work in the districts, without thereby expressing any opinion as to their appropriateness or their advisability.

In the Marquette district we found the upper series there exposed to be as follows: (1) Michigamme slate and schist, and (2) Ishpeming formation. Locally within the Michigamme slate, and apparently near its base, is an iron-bearing horizon. The Clarksburg volcanics, said to be a local phase of the Michigamme formation, were seen at Champion. The basal member of the Ishpeming formation is the Goodrich quartzite. This series, called the upper Marquette series by the United States Geological Survey, has at its base a pronounced unconformity, marked by extensive beds of conglomerate having materials of diverse character. The dominant fragments of the conglomerate at the localities visited are from the Negaunee formation to be mentioned below. The next series is the Middle Marquette series, consisting of (1) the Negaunee formation, (2) the Siamo slate, and (3) the Ajibik quartzite. In the publications of the United States Geological Survey this series was not separated from the series next mentioned, but the work of Professor Seaman has shown that there is a pronounced unconformity, marked by strong basal conglomerates at the bottom of the Ajibik. Below this unconformity is the Lower Marquette series, consisting of (1) the Wewe slate, (2) the Kona dolomite, and (3) the Mesnard quartzite. At the places where we

saw the succession there is a belt of slate between the Kona dolomite and the Mesnard quartzite of such thickness that it might possibly be mapped as a formation if the exposures were more numerous. The members of the United States Geological Survey think that this slate is probably general for the district, as it shows wherever the exposures are continuous from the dolomite to the quartzite. At the base of the Lower Marquette series is an unconformity, marked by conglomerates bearing fragments of all the kinds of rocks seen in the underlying series. Two classes of fragments are especially abundant. These are (1) tuff, greenstone schist, and many kinds of greenstones which belong to the so-called green-schist series of the district, and (2) various kinds of granite and gneissoid granite. Adjacent to the state road south of the city of Marquette the actual contact was seen between the two series, the basal conglomerate resting upon the green schist. The great variety of materials in this conglomerate and the well-rounded character of the fragments left no doubt in the minds of the members of the party that there is a great structural break at the base of the Lower Marquette series.

The lowest group of the Marquette district is a very complex one, which has been designated as the Basement Complex. It consists of two classes of material—the greenstone-schist series, and the granites and gneissoid granites. The greenstone schist series is especially well known through the description of the late George H. Williams, found in *Bulletin 62* of the United States Geological Survey. This series is designated on the maps of the *Marquette Monograph* as the Kitchi and Mona schists. Intrusive in the green schist series are great masses of granite and gneissoid granite. No evidence was seen by the party that any of the granites intrude the sedimentary series above the green-schist series, although Seaman thinks in one place a small mass of granite does intrude the Lower Marquette series. It is believed that the great masses of granite of the district antedate the three series here called Upper, Middle, and Lower Marquette.

In the Penokee-Gogebic district the highest rocks seen are the Keweenawan traps and interbedded sandstones, the bedding of which dips at a high angle to the north. No actual contact between the Keweenawan and the next underlying series was seen, but north

of Bessemer, below the Keweenawan, the next formation is the great Tyler slate formation of the Penokee series, while at Sunday Lake the Keweenawan rests directly on the iron-bearing formation which is stratigraphically below the slate. This relation led the party to infer the existence of an important unconformity between the two. The Penokee-Gogebic, or iron-bearing series, consists of (1) the Tyler slate, (2) the Ironwood formation, and (3) the Palms slate. This Palms slate was seen to rest directly upon granite south of the Newport and Palms mine. At the former locality there is no conglomerate at the base. At the latter locality there is a conglomerate at the base of the slate which, besides containing granite detritus, also contains many cherty fragments supposed to be derived from the next underlying sedimentary series.

East of the Presque Isle River the lower sedimentary succession of the Penokee-Gogebic district was visited, here consisting of (1) cherty limestone and (2) quartzite. The quartzite dips to the north at a moderate angle and rests upon green schist. The two formations were seen in direct contact for a hundred feet or more. The cleavage of the green schist abuts against the bedding of the quartzite at right angles. The quartzite near its base passes into a conglomerate, which, just above the contact becomes very coarse and contains very numerous well-rolled fragments of the immediately subjacent schist. The unconformity at the base of the quartzite could not be more pronounced.

The party nowhere saw the relations of the limestone-quartzite series just described and the Penokee-Gogebic series proper, but they have no reason to doubt the conclusion of the United States Geological Survey that the limestone-quartzite series is the inferior one.

The relations of the green schist, called Mareniscan by the United States geologists, and the granite, which together constitute the basement upon which the determined sedimentary series of the district rest, were not studied by the party. The United States geologists hold that the relations are perfectly clear, and that the granitic rocks are intrusive in the green schist.

In the Mesabi district the succession of the Mesabi series is as follows: (1) Virginia slate, (2) the Biwabik iron formation, and (3)

the Pokegama quartzite. This series dips at a gentle angle to the south. At the base of this series at Biwabik is a conglomerate which rests upon a series of slates and graywacke, the latter in nearly vertical attitude. The unconformity between the two is most pronounced. The slate and graywacke where crossed has a considerable breadth. It flanks a green-schist series. The slate and graywacke formation adjacent to the green-schist is conglomeratic. Many of the fragments of the conglomerate are from the underlying green schists. At the locality visited it could not be asserted that the break between the slate-graywacke formation and the green-schist series is great, although nothing was seen which is contrary to this view. The granite constituting the Mesabi range is reported by the United States geologists as intruding both the green-schist and the slate-graywacke series, but not the Mesabi series. At the east end of the district a newer granite is reported as intruding both the Mesabi and the Keweenawan series, and in the central portion of the district small areas of granite porphyry are reported as antedating the slate-graywacke series.

In the Vermilion district the Upper series, where seen, consists of (1) Knife slates and (2) Ogishke conglomerate. The Ogishke conglomerate contains very numerous fragments of all the underlying formations noted—porphyries, green schists, iron formation, granite—and we have no doubt that there is a great structural break at the base of the Ogishke. The series below this unconformity, the Vermilion series, consists of (1) the Ely greenstone and (2) the Soudan formation. The Ely greenstone is the dominant formation. It is mainly composed of green schists and greenstones, many of which show the ellipsoidal structure described by Clements. The other important formation of the Vermilion series is the Soudan iron formation. The structural relations of the Ely greenstone and the Soudan formation are most intricate. No opinion is here expressed as to their order. The Ely greenstone and the Soudan iron formation are cut by porphyries, and, according to the reports of the United States Geological Survey, are cut in a most complex way by the great northern granite, but the localities illustrating this were not visited. It is worthy of mention that the United States geologists report granite as intruding the Knife slates and Ogishke conglomerates in

the central parts of the district, especially in the vicinity of Snowbank Lake, but this locality was not visited by the party.

In the Rainy Lake district the party observed the relations of the several formations along one line of section at the east end of Shoal Lake and at a number of other localities. The party is satisfied that along the line of section most closely studied the relations are clear and distinct. The Couchiching schists form the highest formation. These are a series of micaceous schists graduating downward into green hornblendic and chloritic schists, here mapped by Lawson as Keewatin, which pass into a conglomerate known as the Shoal Lake conglomerate. This conglomerate lies upon an area of green schists and granites known as the Bad Vermilion granites. It holds numerous large well-rolled fragments of the underlying rocks, and forms the base of a sedimentary series. It is certain that in this line of section the Couchiching is stratigraphically higher than the chloritic schists and conglomerates mapped as Keewatin. On the south side of Rat Root Bay there is also a great conglomerate belt, the dominant fragments of which consist of green schist and greenstone, but which also contain much granite. The party did not visit the main belts colored by Lawson as Keewatin on the Rainy Lake map, constituting a large part of the northern and central parts of Rainy Lake. These, however, had been visited by Van Hise in a previous year, and he regards these areas as largely similar to the green-schist areas intruded by granite at Bad Vermilion Lake, where the schists and granites are the source of the pebbles and bowlders of the conglomerate.

In the Lake of the Woods area one main section was made from Falcon Island to Rat Portage, with various traverses to the east and west of the line of section. The section was not altogether continuous, but a number of representatives of each formation mapped by Lawson were visited. We found Lawson's descriptions to be substantially correct. We were unable to find any belts of undoubted sedimentary slate of considerable magnitude. At one or two localities, subordinate belts of slate which appeared to be ordinary sediment, and one belt of black slate which is certainly sediment, are found. In short, the materials which we could recognize as water-deposited sediments are small in volume. Many of the slaty phases

of rocks seemed to be no more than the metamorphosed ellipsoidal greenstones and tuffs, but some of them may be altered felsite. However, we do not assert that larger areas may not be sedimentary in the sense of being deposited under water. Aside from the belts mapped as slate, there are great areas of what Lawson calls agglomerate. These belts, mapped as agglomerates, seem to us to be largely tuff deposits, but also include extensive areas of ellipsoidal greenstones. At a number of places, associated and interstratified with the slaty phases are narrow bands of ferruginous and siliceous dolomite. For the most part the bands are less than a foot in thickness, and no band was seen as wide as three feet, but the aggregate thickness of a number of bands at one locality would amount to several feet.

We could discover no structural breaks between the above formations of the Lake of the Woods. The various classes of materials —slates, agglomerate, and ellipsoidal greenstones—all seem to belong together. In short, these rocks in the Lake of the Woods seem to us to constitute one series which is very largely igneous or volcanic in origin, but does, as above mentioned, contain some sediments. This series in the Lake of the Woods area is the one for which the term "Keewatin" was first proposed for the greenstone series, Lawson giving as one reason for proposing this name the statement that there is no evidence that these rocks are equivalent with the rocks of Lake Huron described by Logan and Murray as Huronian.

The ellipsoidal greenstone-agglomerate-slate series is cut in a most intricate way by granite and granitoid gneiss, which constitute much of Falcon Island at the southern part of the Lake of the Woods and a great area north of the Lake of the Woods. These relations between the granite and Keewatin were seen on the northwest part of Falcon Island and on a small island adjacent. They were also seen north of Rat Portage. At the latter place the rocks adjacent to the granite are banded hornblende and micaceous schists, very similar to the banded rocks of Light House Point, at Marquette. At Hebe Falls the granite and Keewatin series are seen to be in actual contact, the Keewatin being apparently intruded by the granites, although the relations have often been interpreted as conformable gradations. Going north along the Winnipeg River, the relations

between the two series become perfectly clear. Great blocks of the Keewatin are included in the granite, the masses varying from those of small size to others of enormous bulk. Also the two have intricate relations, which have perhaps been best described as *lit par lit* injection. In short, the relations are those so well described by Lawson for this area.

In the Thunder Bay district we visited especially the areas about Loon Lake and Port Arthur. In the Loon Lake area the succession is as follows: The top series is the Keweenawan, here consisting of sandstone above and conglomerate below, with interbedded basic igneous flows or sills. Below the Keweenawan is the Animikie. The contact between the Keweenawan and the Animikie was seen at two places. At one of these there is an appearance of conformity, but at the other the eroded edges of the Animikie iron-bearing formation are traversed by the Keweenawan beds. At one contact the base of the Keweenawan rests on the Animikie slate, interstratified with the iron formation, and at the other on one of the members of the iron-bearing formation. At both localities the conglomerate at the base of the Keweenawan bears detritus from the underlying series, including both the slate and the iron-bearing formations of the Animikie. The Animikie succession which we saw near Loon Lake includes two phases of the iron-bearing formation with an interstratified belt of slate. The Animikie here has in general rather flat dips, although locally they become somewhat steeper.

Near Port Arthur the higher slate member of the Animikie was visited by a portion of the party, and on previous occasions had been visited by the other members. This is the formation which is agreed by all to rest upon the Animikie iron formation. It is notable as containing the intrusive sills called by Lawson the Logan sills.

At one place near Loon Lake a test pit has been sunk to the bottom of the Animikie, and here at the base of the formation is a conglomerate bearing fragments of the next underlying series—a graywacke slate. This graywacke slate covers a large area, shows cleavage at a high angle, and is evidently an important formation in the district.

The party has no doubt that there is considerable unconformity between the Keweenawan and the Animikie, and a very important unconformity between the Animikie and the graywacke slates.

A portion of the party went north from Port Arthur to see the green-schist and granite series. This was found, but seen only in small volume at the particular area visited. At other times several members of the party have visited larger areas of this green-schist and granite complex north and northwest of Port Arthur in Gorham, Conmee, and other townships, and in the green schists they found an iron-bearing formation analogous in character to the Soudan formation of the Vermilion district. The granites are intrusive in the greenstones.

At no place were the relations between the graywacke slate series below the Animikie and the green-schist granite complex observed.

In the original Huronian area—i. e., the area described by Logan and Murray as extending from near Sault Ste. Marie along the north shore of Lake Huron to Thessalon and northward — we examined a number of crucial localities. At the first of these, about five miles from Sault Ste. Marie, near Root River, we studied the relations of the conglomerate, mapped as lower slate conglomerate by Logan, with the granite. The conglomerate is in a vertical position. We found the upper horizon of the conglomerate near the road to be of moderate coarseness, and to contain many fragments of green schist, greenstone, and granite. The granite fragments increase in prominence and size toward the north, and at the north end of the exposure we have a great granite conglomerate. After an interval of a few paces we found to the north a red granite similar to many of the fragments of the conglomerate. The party has no doubt that the conglomerate rests unconformably upon the granite. This conglomerate, while mapped by Logan as lower slate conglomerate, appears to be above a limestone next to be mentioned, and has been connected by Van Hise and Leith with rocks like the red quartzite belonging above the limestone, and they believe it to be the upper slate conglomerate rather than the lower slate conglomerate, although the overlapping recent lake deposits prevent the connection by actual areal tracing. A short distance east of the point where the conglomerate is next to the granite and north of the great mass of the conglomerate is a belt of limestone which continues east for perhaps half a mile. North of this limestone is conglomerate, and still to the north, granite. This northern conglomerate is very similar to the conglomerate south of the lime-

stone, and two interpretations are possible as to its position: it may be regarded as the lower slate conglomerate under the limestone, or it may be regarded as an equivalent to the conglomerate south of the limestone, being repeated by an anticline or possibly a fault. The limestone has a steep dip to the north, and, accepting either alternative, it must be regarded as overturned.

We next visited the abandoned limestone quarry north of Garden River station. Here we found the conglomerate, marked by Logan as the upper slate conglomerate, within a few paces of the limestone. This conglomerate is in all respects similar to the average of the conglomerates before mentioned, except that it contains very numerous limestone fragments. The party has no doubt that the limestone formation was laid down, and that a considerable erosion interval occurred before the deposition of the conglomerate upon the limestone. The slate-conglomerate belt north of the limestone was examined, and while it was not found in contact with the limestone, it was seen to increase in coarseness as the limestone is approached, and across the little ravine which separates the conglomerate from the limestone it was found to contain numerous limestone fragments. We therefore conclude that the rock on each side of the limestone is the upper slate conglomerate, the structure probably being anticlinal, possibly with faulting. This conclusion suggests that the same relation obtains at the Root River locality above described.

On the limestone point on the east side of Echo Lake we found the following ascending succession, with monoclinal dip to the southeast: (1) white or gray quartzite, grading through graywacke into (2) a thin belt of conglomerate not exceeding twenty feet in thickness and containing numerous granite fragments. Above the conglomerate is (3) limestone in considerable thickness, and over this (4) the upper slate conglomerate. This last is a thick formation. The upper conglomerate is very coarse near the limestone, and becomes finer in passing away from the limestone along the lake shore. Like the conglomerate near Garden River, it bears very numerous limestone fragments, the evidence of which is beautifully seen at the lake shore, where the water has dissolved many of them completely and others in part. The ledge thus presents a deeply pitted surface, many of the pits being several inches in depth.

On the west side of Echo Lake we ascended the prominent bluff next north of the west limestone point, and here found the formation nearly horizontal, but dipping slightly into the hill. The quartzite in this position composes the greater part of the bluff. A short distance from the top we found the quartzite grading upward into a graywacke-like rock, and this into a conglomerate which contains granite and green-schist fragments; indeed, it is typical slate conglomerate. This conglomerate is only a few feet in thickness, and above it appears a siliceous limestone, and above this, normal limestone like that of Garden River and the east side of Echo Lake. The total thickness of the limestone here seen was probably not more than fifty feet, and of the conglomerate below, not more than thirty feet. The lower five hundred feet or more of the bluff is the white quartzite.

The other bluffs on the west side of the lake were not visited by the party, but Leith, Seaman, and Van Hise have examined each of these bluffs, and found the succession above given to obtain upon each prominent bluff, with the exception that on the next bluff to the north the limestone is wanting, so far as observed. The limestone is also in greater force on some of the other bluffs, but is always subordinate in thickness to the quartzite. It thus appears that the great formation on the west side of Echo Lake is the quartzite; that the limestone above appears, not as a single belt, but as a number of synclinal patches often capping the hills; and that the conglomerate showing both north and south of the limestone is a very thin formation between the quartzite and the limestone, and is, therefore, the lower slate conglomerate.

Our observations from Root River to Echo Lake convince us that there is a considerable structural break in the Huronian. The upper series includes the following formations of Logan, viz.: white quartzite, chert, and limestone, yellow chert and limestone, white quartzite, red jasper conglomerate, red quartzite, and upper slate conglomerate. The lower series includes the lower limestone of Logan and the lower slate conglomerate, white quartzite, and gray quartzite. North of Thessalon the two series are represented by Logan and Murray as being separated by a fault. Here the distribution may be explained by the unconformity mentioned, but

it is also entirely possible that the relations are due to faulting or to both unconformity and faulting.

Four miles east of Thessalon on several islands off the coast is a great conglomerate, mapped by Logan and Murray as gray quartzite. This conglomerate was found to rest unconformably upon the granite, the actual contact being observed upon one island opposite the northwest quarter of Sec. 12 of the Township of Thessalon. The fragments in the conglomerate are well rounded and are largely granite, but there are also numerous pebbles and bowlders of greenstone and green schist. On several islands adjacent to the conglomerate the massive granite includes many fragments of greenstone and green schist, showing the granite to be intrusive into a greenstone formation. Thus in the complex against which the conglomerate rests we have a source both for the granite and greenstone pebbles and bowlders. To the northwest the conglomerate grades up by interstratification into a quartzite. About a quarter of a mile west of the conglomerate, near the north end of a point, the quartzite is found to become a fine conglomerate, and to rest against greenstone which is cut by a large granite dike. The greenstone shows ellipsoidal parting. The granite dike strikes toward the conglomerate and the quartzite, but it dies out into a depression showing no rock, which continues to the quartzite some fifty or sixty feet distant. The quartzite and conglomerate strike directly across this depression, showing continuous exposures, and are not cut by granite. The relations here are believed by certain members of the party to show clearly that the quartzite and conglomerate rest unconformably upon the greenstone, but other members felt that this conclusion is not certain. The conglomerate and gray quartzite are cut by greenstone dikes. Similar rocks also cut the Thessalon series referred to below.

The rocks called green chloritic schist by Logan (3*c*) will here be called the Thessalon series. This series consists of ellipsoidal greenstones, amygdaloids, agglomerates, and massive greenstones. No undoubted sediments were observed in the series. The relations of the Thessalon series to the granite were observed southeast of Little Rapids, and it was found that the granite cuts the greenstone series in an intricate fashion. The belt of gray quartzite, mapped as extending inland for a number of miles between the Thessalon series

and the granite, was found to be absent at this locality. Two or three miles east of Thessalon, felsite and granite in considerable masses were found to intrude the Thessalon series. At one place several felsite or granite dikes were observed to cut both the agglomerates and ellipsoidal greenstones. From the relations observed, the party had no doubt that the conglomerate islands east of Thessalon belong unconformably upon the granite, and they think it probable (Van Hise would say highly probable) that the quartzite and conglomerate rest unconformably upon the Thessalon series, mapped as green chloritic slate by Logan and Murray. It is regarded as probable that the white quartzite below the lower slate conglomerate northwest of the Thessalon series which is adjacent, and is shown by its dip to rest upon the Thessalon series, is separated from that series by an unconformity, but no direct evidence of such relation was observed.

The Thessalon series should be excluded from the Huronian if, as believed, the unconformity just mentioned exists. If this series be excluded, the Huronian of Lake Huron consists of two series, an Upper Huronian and a Lower Huronian. The Upper Huronian extends from the top of the series, as given by Logan and Murray, downward to and including the upper slate conglomerate; and the Lower Huronian extends from the main limestone formation to the gray quartzite, including its basal conglomerates. In the area mapped by Logan on the north shore of Lake Huron the Laurentian consists of granite and gneissoid granite, with subordinate inclusions of greenstone.

We do not feel that our examination of the Lake Superior region was sufficiently detailed to warrant an attempt at correlation of the individual formations of the various districts. There are, however, certain general points which seem to be reasonably clear, and about which there is no difference of opinion between us. These are as follows:

There is an important structural break at the base of the Keweenawan. The term "Keweenawan" should include substantially all of the areas which have been thus mapped, or mapped as Nipigon, by the Canadian and United States Surveys, and the State Surveys of Michigan, Minnesota, and Wisconsin.

Below the Keweenawan is the Huronian system, which in our opinion should include the following series: In the Marquette district, the Huronian should include the Upper and Lower Marquette series, as defined in the monographs of the United States Geological Survey, or the Upper, Middle, and Lower Marquette series, as given in the previous paragraphs. In the Penokee-Gogebic district, the Huronian should include the series which have been called the Penokee-Gogebic series proper, and the limestone and quartzite which have local development, and which we visited east of the Presque Isle River. In the Mesabi district, the Huronian should include the Mesabi series proper, and the slate-graywacke-conglomerate series, unconformably below the Mesabi series. In the Vermilion district, the Huronian should include the Knife slates and the Ogishke conglomerates. In the Rainy Lake district, the Huronian should include that part of the Couchiching of the south part of Rainy Lake which is limited below by basal conglomerate as shown at Shoal Lake. In the Thunder Bay district, the Huronian should include the Animikie and the graywacke series in the Loon Lake area. In the original Huronian area, the Huronian should include the area mapped by Logan and Murray as Huronian, except that the Thessalon greenstones should probably be excluded.

Unconformably below the Huronian is the Keewatin. The Keewatin includes the rocks so defined for the Lake of the Woods area and their equivalents. We believe the Kitchi and Mona schists of the Marquette district, the green schist (Mareniscan) of the Penokee-Gogebic district, the greenstone series of the Mesabi district, the Ely greenstones and Soudan formation of the Vermilion district, the part of the area mapped as Keewatin by Lawson in the Rainy Lake district not belonging structurally with the Couchiching, and probably the Thessalon greenstone series on the north shore of Lake Huron, to be equivalent to the Keewatin of the Lake of the Woods, and, so far as this is true, they should be called Keewatin.

For the granites and gneissoid granites which antedate, or protrude through, the Keewatin, and which are pre-Huronian, the term "Laurentian" is adopted. In certain cases this term may also be employed, preferably with an explanatory phrase, for associated granites of large extent which cut the Huronian, or whose relations to the Huronian cannot be determined.

The following succession and nomenclature are recognized and adopted:

CAMBRIAN—Upper sandstones, etc., of Lake Superior

Unconformity

PRE-CAMBRIAN

Keweenawan (Nipigon)[1]

Unconformity

Huronian { Upper (Animikie)

Unconformity

Middle

Unconformity

Lower }

Unconformity

Keewatin

Eruptive contact

Laurentian

Alphabetically signed by the committee as follows:

FRANK D. ADAMS,
ROBERT BELL,
A. C. LANE,
C. K. LEITH,
W. G. MILLER,
CHARLES R. VAN HISE,
Special Committee for the Lake Superior Region.

[1] Dr. Lane dissents as to the position of the Keweenawan as follows:

"The use of pre-Cambrian above does not imply unanimity in the committee with regard to the pre-Cambrian correlation of the Keweenawan—a topic the committee as such did not investigate."

THE ACCORDANCE OF SUMMIT LEVELS AMONG ALPINE MOUNTAINS: THE FACT AND ITS SIGNIFICANCE[1]

REGINALD A. DALY
Ottawa, Canada

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THE STATEMENT OF SUMMIT-LEVEL ACCORDANCE

Neither statistics nor eloquence are required to recall one principle in the interpretation of lofty, alpine mountains; their students must be content to attack their mighty problem in a piecemeal fashion. The alps of the world are tangles in structure and the stony records of tangles of prodigious events. It is no wonder that their form has so long baffled the evolutionist. He has often had to turn back from the attempt to carry into the high mountains the same ground principles of land-building and land sculpture which have of late years been so successfully explaining the simpler forms of the land.

[1] Published by permission of the Canadian commissioner, International Boundary Surveys.

If, then, advance in the interpretation of the world's great ranges ca
be really made in any one direction, such advance must be welcome
as a step toward the distant, ultimate goal of complete knowledge of the earth. Not only for the sake of the single study itself, but perhaps still more for the sake of putting no obstacle in the way of related interpretations, it is well that close scrutiny be fixed on every such subordinate theory. No further reason is necessary for additional field-work on a problem now in discussion concerning the physiography of mountains, namely, the meaning of the generally observed accordance of levels among the higher summits of an alpine range.

The word "accordance" is used advisedly. "Equality" of heights is not meant by those observers who have given the question the best attention. For limited areas "subequality" of the summits is a fact, but over wider stretches, and especially over the whole of a single range, even subequality fails, and the accordance takes the form of sympathy among the peaks whose tops in companies or in battalions rise or fall together in imaginary surfaces often far removed from the spheroidal curve of the earth. In general, the imaginary surface which will include the higher summits of peaks and ridges in an alpine range has the form of a low arch, highest in the interior of the range and elongated in the direction of the main structural axis of the range. Subordinate, but usual and systematic, complications in the form of this imaginary surface are found in transverse crenulations which alternately depress and raise the surface from its average out-sloping position on the margin of the great arch. The axes of these transverse depressions are often suspiciously coincident with existing drainage courses.

There is, then, at least one orderly element in the "chaos" or "tumbling sea" of mountains visible from a dominating point in any one of a goodly number of alpine ranges. The accordance of summit altitudes has been noted in the Alps, in parts of the Caucasus, in the Pyrenees, in the Sierra Nevada of California, in the Alaskan ranges, in the Canadian Selkirks and Coast Range, and in the American Cascade Range.[1]

[1] In the present paper the term "alpine range" is used to signify a range possessing not only the rugged, peak-and-sierra form of the Swiss Alps, but, as well, the internal

The fact of accordance is established, while the theories of explanation are very various. That they need critical examination and sifting is clear, not only for the sake of the important fact of accordance itself, but also for the reason that these theories involve widely diverging views on great physiographic revolutions. Geological history in long chapters is thereby as expressly implied as it would be by the interpretation of purely stratigraphic evidences, illustrating over and over again the truth that both classes of evidences are required in building up a complete history of the earth. Not only do these theories involve premises regarding great denudations, but, as well, a multitude of details concerning river history and the evolution of individual mountain massifs. There are likewise involved correlative views of the physiographic development of the neighboring regions, both on the large scale and in details. Geographic description and nomenclature should be controlled by reference to the correct theory or theories of land-form origins. Finally, large conclusions concerning the origin of the force of mountain uplift must follow in the wake of certain of the hypotheses already announced to explain the phenomenon of accordance in summit levels. The attempt has even been made to connect the origin of fractures and of mineral veins with the specialized kind of crustal movement hypothecated by one explanation of this accordance.[1] There are thus abundant reasons for coming to a wise decision as to the best explanation of the fact.

THE VARIOUS EXPLANATIONS OF ACCORDANCE

The hypotheses dealing with this sympathetic attitude of alpine summits may be classified on the basis of the logical explanation of an organism. (*a*) How far is the feature in question due to *inheritance?* (*b*) How far is it due to *spontaneous development* in the present environment? A review of the hypotheses shows, everywhere and naturally, emphasis placed on erosion, but the writer believes that the possibilities of inheritance are only partially worked

structures incidental to intense crumpling, metamorphism, and igneous intrusion as exemplified in the Swiss Alps.

[1] A. C. Spencer, *Transactions of the American Institute of Mining Engineers*, October, 1904, p. 35.

out, and, again, that the methods of spontaneous development are not yet brought into the proper balance for final discussion or decision of the problem.

I. EXPLANATIONS BY INHERITANCE

The accordance of summit levels may well suggest the analogy of moderately or maturely dissected plains underlain by rocks of horizontal structure. Often with such plains there is little or no doubt of the original, simple form before erosion had produced the intaglio forms of dissection. The common agreement of altitudes among the hilltops of the sculptured plain is manifestly the effect of inheritance from the early, initial stage of the plain's history. Is there anything comparable in the derivation of existing alpine mountain ranges? Their almost infinite complexity of structure due to folding, blocking, thrusting, igneous intrusion, and metamorphism forbids that the analogy shall be anything more than an analogy; yet the question is raised whether, at some earlier stage in the history of each range, there may not have been produced a more or less perfect accordance of summit levels which would, through ordinary processes of erosion, furnish similar accordance in the later stages of the history, including the present stage. Three answers may be proposed to the question.

1. *The peneplain theory.*—The explanation which has, on the whole, won most attention from American students of the problem is that now familiar to physiographers as the peneplain theory. By this view the alpine range is supposed to have passed through the paroxysmal epoch of uplift by crumble, faulting, and thrusting; then through a period of denudation so prolonged that the once lofty range was thereby reduced to a gently rolling lowland, the surface of which stood near sea-level or the general base-level of the region. In every full published discussion the author favoring the peneplain theory has regarded it as probable or as certain that subordinate residual hills or mountains, monadnocks, rose above this peneplain.

A second chief premise necessary to the theory is that of a broad, massive warping of the peneplained surface; the major axis of upwarp being roughly coincident, or parallel, with the present topographic axis of the range. The existing details of relief are then regarded

as due to inheritance, after mature erosion, from the initial peneplained surface with which the present physiographic cycle opened. The sculpture of the unwarped surface is by some attributed largely to streams definitely controlled in their direction of flow by the general slopes of the warped peneplain, i. e., consequent streams. In the Cascade Range of Washington, Messrs. Willis and Smith make the special supposition of transverse upwarps and downwarps complicating the initial form of the uplifted Pliocene peneplain from which the present range is supposed to have "descended." Mr. Spencer has deduced peneplanation and arch-warping for the Coast Range of British Columbia. He is therewith compelled to place in a different, antecedent, class a half-dozen of the chief rivers cutting clear across the range.[1] Revived subsequent streams—that is, those developed on weak rock-belts during peneplanation and incited to still deeper cutting on those belts by the upwarping—must form a third kind of corrasive agents. Following the upwarping, local and general glaciation will still further greatly complicate the scheme of drainage.

One may feel but little doubt that the peneplain theory is sound when applied to the more or less classic cases of the Appalachian Piedmont, the New Jersey, New England, and Acadian plateaus, the plateaus of the Rhine, of Bohemia, and of central France and Brittany. In each one of these instances the already well-discussed criteria of the uplifted and sculptured peneplain are apparently well satisfied. Each region shows excellent examples of the remnant, high-lying plateau flats truncating rocks of complex structures. Often the criterion of adjusted drainage is admirably fulfilled. Where glaciation has not disturbed the normal conditions, the plateau remnants of the former lowland still bear the deep residual soils expected on the theory. Finally, in none of these regions is the geological history of adjacent physiographic provinces discordant with the peneplain theory.

If any one of the criteria can be taken as more positive than the others, it is that of extensive plateau remnants of the peneplain surface. Yet it is clear that even those remnants will lose their flat-topped character with prolonged erosion. The perfectly mature

[1] *Bulletin of the Geological Society of America*, Vol. XIV (1903), p. 125.

dissection of the former lowland will greatly weaken the proofs of approximate planation near base-level at the end of a former physiographic cycle. It is expected, however, that subequality of accordance of summit levels will long characterize the individual mountains produced by the intaglio cutting of the upwarped peneplain. Conversely, where such accordance of summit levels in structurally complex mountains is found, it is legitimate, if not necessary, to place ancient peneplanation as a possible stage in the topographic evolution.

This has been the principal criterion on which Messrs. Russell, Smith, and Willis have based wide-reaching conclusions regarding the development of the main Cascade Range of Washington. Mr. Willis has mapped a few, very small, flattish areas on summits which he considers as possible remnants of the peneplain.[1] Mr. Smith states that no remnant of it has been discovered in the large area of the Snoqualmie Quadrangle (U. S. Geological Survey map) which he has particularly studied.[2] Mr. Russell came to a similar conclusion regarding the high Cascades of northern Washington.[3] Geology and physiography owe much to these authorities for their systematic and masterly presentations of the theory which every worker in the general geology of the Cascades must entertain and carefully discuss. The problem is there, as in other similar ranges, peculiarly difficult because it is precisely in mountains of alpine height that the records of former peneplanation are most quickly rubbed out; it is there that positive criteria are reduced to a minimum. One must therefore especially welcome such constructive work as is represented in the memoirs recently published concerning a typical alpine range, the high Cascades.

The peneplain theory does certainly render the accordance of summit levels among alpine peaks intelligible. Yet that fact is far from proving the truth of the theory as applied to alpine ranges. This will be especially clear if it can be shown that there are, and have been, other agencies at work capable of producing the actual degree of accordance in the summit levels of such a range as the high Cascades. The writer believes that further constructive work along

[1] *Professional Paper No. 19*, U. S. Geological Survey (1903), Plates 16 and 17.

[2] *Ibid.*, p. 34.

[3] *Twentieth Annual Report*, U. S. Geological Survey, Part II (1900), p. 141.

the lines of the peneplain theory is at present not so necessary as a critical inquiry into alternative hypotheses. For the same reason, a concrete criticism of the views on which have been based the attempts to establish the peneplain theory for special alpine ranges will here be left in abeyance.

The other possible explanations of accordance, including those already published as well as others which have occurred to the writer in the course of field-work, have one important feature in common—a feature which places all of them in opposition to the peneplain hypothesis. That hypothesis demands at least two cycles of erosion in the history of the mountain range; one cycle essentially completed at the time of penultimate extinction of relief, with a second cycle, the present one, advanced to the mature stage of dissection. Involved with this premise of multiple cycles is the conception that the present cycle has been initiated by a quite different kind of mountain-building from that which first gave the range its great altitude. Broad, relatively gentle warps, producing on the average an arch elongated in the axis of the existing range, form the kind of movement demanded in the uplift of the peneplained area, while intense plication, thrusting, and blocking gave the range its internal structures and its original relief. In short, the peneplain hypothesis stands in contrast with all the other hypotheses in placing peneplanation and subsequent warping among the necessary stages in the development of the existing mountains. Unequal in strength as these alternative hypotheses may be, they have the common characteristic of excluding a great denudation and a specialized kind of crustal movement from the list of complications in the history of the range. It is most important to observe that this common characteristic, coupled with the fact that the alternative explanations are not mutually exclusive, gives them cumulative force against the peneplain hypothesis, when applied to truly alpine mountains.

2. *Hypothesis of original rough accordance of summit levels, due to isostatic adjustment.*—Basal to all of the alternative hypotheses is the inquiry as to the original form of the range at the geological moment when paroxysmal folding of its rocks was practically completed. It is self-evident that the term "original" is here used arbitrarily, but the strain on language may be permitted in thus conven-

iently naming and emphasizing a principal epoch in the early history of the range.

At first sight one may be surprised to find this accordance of summit levels among high mountains of complex structure. Surprise should be tempered, however, by the consideration that the original relief was not even approximately determined by constructional profiles deducible from existing structures.

It is, for example, highly improbable that the "reconstruction" of a great alpine anticline through a study of its denuded roots can represent the original height of its crest above sea-level. Nor is it legitimate to conclude from the great shortening of the transverse axis of the range by the enormous tangential pressures that orogenic blocks of indefinite height could have been produced. Overthrusting, upthrusting, folding, mashing, and igneous intrusion have often occurred on such a scale, that were it not for other and inhibiting causes, differential elevations perhaps forty or fifty thousand or more feet in relative height might have resulted. No geologist believes that local blocks of such height have entered into the construction of any terrestrial range. Erosion during the absolutely slow, though relatively rapid, growth of the range has often been appealed to as sufficient to explain the lack of such heights in even the youngest alps of the world. But not sufficient emphasis has been placed on the quite different control of isostatic adjustment accompanying and following the paroxysmal uplift of orogenic blocks. Single steep slopes of possibly thirty thousand feet might, indeed, then exist if they were underlain by the strongest granite, which likewise formed the underpinning of the whole adjoining district, that granite being throughout at the temperatures of ordinary rock-crushing experiments. But such towering masses are highly improbable for weaker rocks which would crush down under the supposed conditions, and wholly impossible for mountain blocks overlying material as plastic as that which composes the original basement of an alpine range. The strength of the main mass of the range is diminished by the inevitable rise of subsurface temperatures with crumpling and mashing. It is the rule with alpine ranges that intrusions of hot magma on a huge scale either accompany or very soon follow the chief paroxysms of folding. In either case, and not only over the areas where denudation has exposed the intru-

sives, but also over much wider areas about the downwardly expanding bases of the batholiths, the heat of the intrusions still further increases the plasticity of the basement on which the mountains are growing. The weakness of the underpinning is further manifest in the case of such ranges as the Cascades or the Coast Range of British Columbia, so largely formed of granitic magma injected in a highly plastic, if not thoroughly fluid, state during or just after the last great period of plication in those ranges.

The conclusion seems unavoidable that the tendency of tangential force to erect orogenic blocks projecting much higher into the air than Mount Everest itself is operative only up to a certain critical point. Beyond that point the increasing weight of the growing block and the increasing plasticity of its basement call in another kind of movement due to the gravitative downcrushing of the block. As a whole, or in fragments separated from each other by normal faults, the block will assume a shape and position suitable to static equilibrium for the whole range. The range might conceivably find that equilibrium when the entire uplift has attained the form of an elongated arch accidented by already roughly accordant mountain summits. At any rate, subequality of height might characterize large areas.

This whole phase of gravitative adjustment forms a problem clearly indeterminate in the present state of geological physics. Critical laboratory experiments have yet to be devised, and careful, special field-work devoted to the problem, before it can attain even an approximate solution. So far as it goes, however, gravitative adjustment of the kind just described aids all the other processes tending toward summit-level accordance.

3. *Hypothesis of original rough accordance, due to differential erosion during the period of alpine plication.*—Co-operating with isostatic adjustment is the effect of the special erosive attack on each rising block from the moment it once begins to dominate its surroundings. On the average, the forces of weather and waste are most destructive on the summits of this time, as they shall be through all the subsequent history of the range as an alpine relief. Denudation is in some direct ratio to the height of uplift. Higher summits are thereby reduced, while lower ones are still growing under the stress of mountain-building. How far erosion thus checks the upward growth

of the rising massifs probably cannot be measured, but such differential destruction must develop still further the rough summit-level accordance already in part established by isostatic adjustment.

4. *Conclusion.*—The downcrushing of higher, heavier blocks with the simultaneous rise of their lower, lighter neighbors, coupled with the likewise simultaneous, specially rapid loss of substance on the higher summits, form a compound process leading toward a single, relatively simple result. In both the architecture and the sculpture of her alpine temple, Nature decrees that its new domes and minarets shall not be indefinitely varied in height. Such accordance as they have among themselves will be preserved and accentuated as her chisels fashion new details on the building. The accordance of the present time in any alpine range is in part inherited from what, in this paper, has been called the "original" form of the range. The original form meant a first approximation to the result; the later, spontaneous modification of that form means a second approximation to perfect accordance.

The composite explanation.— In passing to an analysis of erosion events following the epoch of folding, we are, therefore, illustrating the cumulative forces of all the hypotheses so far announced as alternative with, and as against, the peneplain hypothesis for truly alpine ranges. By the peneplain hypothesis, the accordance of summit-levels was most perfect in the initial stage of the physiographic cycle begun by the upwarping of the peneplain; by that hypothesis mature dissection of the range tends to destroy something of the initial accordance. The alternative, composite explanation, already in part outlined, involves the conclusion that the accordance tends to become more and more perfect as the stage of mature dissection of the newly folded range is reached. The question remains whether the accordance inherited from the forms original from the epoch of plication may be so much further developed by subsequent erosion in the physiographic cycle initiated by that plication, as to give the amount of accordance actually observed in the existing range. If the answer be affirmative, the second inquiry becomes imperative as to the relative merits of the peneplain and composite hypotheses when applied to individual ranges. For reasons given on a previous page, the second inquiry is not specially raised in the present paper.

II. THE SPONTANEOUS DEVELOPMENT OF SUMMIT-LEVEL ACCORDANCE

1. *Spontaneous development by isostatic adjustment.*—The last paroxysm of crumple and upthrust in the young alpine range has occurred. Henceforth its forms are to be determined chiefly by erosive processes—yet not altogether so. Several authors have suggested that the leveling influence of gravity is not only manifest in the piecemeal carriage of rock fragments out to the piedmonts, or finally to the sea; but that also the very accordance of summit levels is in large part related to gravitative adjustment on a large scale.[1] Where, for any cause or causes, denudation significantly lowers a localized area of the range faster than neighboring areas of the same altitude, the former area will tend to rise, the surrounding region to sink, so as to reproduce conditions of equilibrium in the range. This view entails belief once again in the principle of isostasy. It must be admitted that the ground has only been broken in the important field of inquiry as to crustal sensitiveness. The harvest of field and experimental observations has not yet been reaped in volume sufficient to enrich geological science with definite knowledge on the matter. But such facts as the apparent isostatic recoils of the earth's crust after the melting away of the Scandinavian, Labrador, and British Columbia Cordilleran ice-caps, and the notable increase of dips at the feet of the High Plateaus of Utah and Arizona, as described by Major Dutton[2], are among those already recorded in favor of a sympathetic entertaining of the isostatic doctrine. The appeal to the principle in the present case is all the more worthy because of the long continuance of the special plasticity belonging to the very slowly cooling basement of a recently folded alpine range.

2. *Metamorphism and igneous intrusion in relation to the degradation of mountains.*—It is a truism that the rocks of any alpine range vary enormously in composition and structure. It is quite as true that their resistance to weathering and wasting is far less variable. In hundreds of square miles together, the geologist may map gneisses, schists, granites, diorites, marbles, quartzites, or ancient lavas, several or all of these occurring in great masses, and yet he may not be able to ascertain by manifest field evidence that any one of the

[1] See discussion in Penck's *Morphologie der Erdoberfläche.*

[2] *Monograph II*, U. S. Geological Survey (1882), p. 47.

formations is more resistant to the weather than an adjacent formation. That experience is common in the alpine districts where accordance of summit levels has been described. The implication is that the real differences in power to resist attack are of a low order among the rocks of these districts. The writer has often been struck with this fact in the course of field-work in the Coast Range and Selkirks of British Columbia. There, as generally, the phenomenon must be attributed mainly to wholesale metamorphism. This relative homogeneity among the rocks must be regarded as playing an important part in the preservation of summit-level accordance. Whether inherited or not, accordance will be clearly favored by homogeneity.

Secondly, the original upper surface of the zone of intense metamorphism may be conceived as much less uneven than the outer surface of the original range. Mr. Van Hise has shown that pressure is the principal control in the metamorphism of the zone of rock-flow.[1] In the present case, pressure is applied by tangential force and by the weight of individual massifs. The former is in dominant control, as shown by the generally steep dips of planes of schistosity. The lines of force in the tangential pressure are, on the average, not far from horizontal. In the later stages of the period of plication the master-lines of that force pass beneath structural depressions in the range. During the same time constructional massifs will largely escape the maximum squeezing which affects their bases. The weight of each massif will, however, cause the metamorphism to extend upward locally in some degree. The upper surface of the metamorphic core of the massif will have a flatter and, probably, a more regular profile than the rugged land surface above. The composition of the two forces due to weight and tangential pressure should, then, tend to produce a relatively simple upper surface for the whole zone of metamorphism. The surface will be a flat arch as a whole, but locally bearing subordinate domes of low curvature. Along with these subordinate domes must be others of similar low curvature due to the thermal metamorphism of batholiths.

Many of the great intrusive bodies of alpine ranges had originally themselves a demonstrably dome-like form with broad, flattish tops.

[1] *Monograph XLVII*, U. S. Geological Survey (1904), p. 43.

The foregoing statement of a difficult theme is brief, but it suffices to suggest the bearing of metamorphism and intrusion on the question of accordance. In what has been defined as its original state, an alpine range was composed of a hard, comparatively homogeneous core covered with a relatively thin veneer of already somewhat eroded, unmetamorphosed rock. The core is to be conceived as having an upper, limiting surface, with the form of a long, flat arch bearing subsidiary, low, broad, boss-like arches and domes. The erosion of the unmetamorphosed cover will go on apace. The erosion of the core, the main mass of the range, will progress much more slowly. Erosion may thus sweep away wide areas of the cover before the individual mountains between cañons sunk in the core have suffered significant loss of height by denudation. In such areas accordance of summit levels would henceforth be expected because of the original flattish tops of the core, and because of the comparative homogeneity of the core-rocks. For the same reasons, accordance among the summits of mountains cut out of a granite batholith would be expected. Where, however, the granite is distinctly harder than the surrounding metamorphics, there would not be simultaneous accordance with the summit levels of the metamorphic mountains, except for causes other than the two just described. As the composite explanation of accordance is further outlined, it will be seen that such other causes may operate effectively in some cases. Yet the common, special dominance of granite peaks in a truly alpine range agrees as well with the composite explanation as it does with their reference to the class of monadnocks on the peneplain theory.

3. *The influence of local glaciation on summit altitudes.*—Hitherto no detailed distinction has been necessary among the varied phases of erosion. All subaërial agencies of destruction combine their effects to establish so much of summit-level accordance as is due to erosion with consequent isostatic adjustment. Each of the agencies may take a part in the uncovering of the hard, metamorphic core of the range. Throughout the entire history of the range, however, special kinds and conditions of denudation independently do important shares of work in trimming the range to uniformity or accordance of summit levels. To ascertain the value of their work we must take the highland view. A few decades ago, when the power

of river corrasion was first adequately realized, the lowland view of earth sculpture became fruitful. It has led to the correct interpretation of land forms in every continent. Still later, the highland view that the alps of the world owe much of their form to conditions of erosion quite peculiar to high mountains, was first clearly taken by Penck, Dawson, Richter, and others. That their generalization came later than the brilliant statement of general erosion by Gilbert and Powell is natural, for man is a dweller in the lowlands; but science must know no such subjectivity. In the future the highland view must be sharpened and extended.

Local glaciers are characteristic of lofty, alpine mountains. High-lying cirque glaciers exist today by the hundreds in the Swiss Alps, by the thousands in the alps of British Columbia and Alaska. Pleistocene glaciers in vastly greater number and erosive power covered those same regions and, in fact, all the others where summit-level accordance in really alpine mountains has been described. Is there any connection between such glaciation and accordance?

The interesting problem of the origin of cirques or corries is not yet fully solved, but that they, by a vast majority, have been chiefly formed through glacial excavation is certain. In each glacier there are two loci of maximum erosion; one at the head of the glacier where the great *bergschrund* separates the ice from the solid rock of the head-wall; the other beneath the central zone of the glacier itself some distance upstream from the foot of the glacier. One result, noteworthy in the present connection, is to drive the head-wall of the growing cirque farther and farther into the mountain. In the nature of the case, it will be the higher peaks which are most vigorously attacked. From every side, it may be, comes the attack on the massif which, for any cause, specially projects above the general level of the range. Owing to the rapidity of the ice-erosion, that summit must tend to fall and reach something like accordance with its formerly lower, unglaciated or but lightly glaciated neighbors.

There seems to be no possible doubt that existing glaciers are thus working favorably with all the other methods of spontaneously producing summit-level accordance. How much more important has been the product of ancient glaciations in Europe and in America! Richter even makes local glaciation of the Pleistocene period

responsible for most of the peaked and serrated topography of the Swiss mountains. He supposes that in pre-Pleistocene times the range had the comparatively smooth, flowing profiles of well-graded mountains; that the present ruggedness is mostly due to the recession of head-walls in cirque-making.[1] The view may be extreme, but it illustrates the importance which the distinguished European physiographer attaches to the work of local glaciers. Their gnawing action is just as manifest about the countless glacier-beds among the highest peaks and sierras of the Rockies, Selkirks, and Coast Range of British Columbia, of the Washington Cascades, of the mighty ranges of Alaska. In all these fields the highest peaks and ridges long suffered specially powerful attack, as they alone stood high enough to wear the fatal belts of *bergschrund*. During the ice period, they were nunataks and lost substance like nunataks; the loftiest peaks losing most, the lower ones with less linear extent of *bergschrund*, losing proportionately less. Peaks and ridges not penetrating the general surface of the Cordilleran glacier lost nothing by special *bergschrund* attack.[2]

It is certain that this differential erosion was long continued during the Pleistocene period in each of the ranges where accordance of summit levels has been discussed. There is every reason to suppose that like conditions and like results would characterize still earlier glaciations.

For the present purpose it is not necessary to inquire as to the deepening or other modification of main valleys in the range. Important as may be such valley changes to the future scenery of the range, they cannot have anything like the same control over summit altitudes as the direct trimming down of the summits by glacier heads. Moreover, head-wall recession among the higher summits continues throughout the whole epoch of glaciation; the excavation of the main valleys occurs only during maximum glaciation.

In summary, then, it may be said that partial explanation for

[1] *Petermann's Mittheilungen, Ergänzungsheft* No. 132, 1900.

[2] Compare the views of W. D. Johnson and G. K. Gilbert, as announced in the *Journal of Geology*, December, 1904. The special glacial attack on the highest summit of the Big Horn Range (Cloud Peak) is excellently illustrated in the well-known paper by Matthes, *Twenty-first Annual Report*, U. S. Geological Survey, Part II, 1899–1900, Plate XXIII.

summit-level accordance is to be sought in a special, characteristic control of alpine climates. In general, the climate of high levels is a glacial climate. In general, glacial erosion is very great and the bulk of it is high-level erosion. In general, local glaciers and glacial erosion are most abundant and long-lived about the highest summits. One net result of glaciation is to cause the specially rapid wastage of those summits and to produce rough accordance among the peaks.

4. *The influence of the forest cap on summit altitudes.*—Climate not only breeds glaciers in the high levels of an alpine range; it normally determines a more or less well-defined tree-line. The treeless zone is always more extensive in area than the glacier-bearing zone, but the upper limit of trees is often not far from coincident with the lower limit of the zone of cirque glaciers. It is logical to find here a place for the theory that widespread accordance of summit levels in an alpine range is related to the differential rate of erosion above and below tree-line. The theory is so well known that it needs no special detailed statement in the present paper. Let it suffice to recall the principal reasons why denudation is faster above tree-line than below, and once more note the inevitable conclusion from that fact. Again we must take care to adopt the highland view of erosion. It cannot be too strongly emphasized that the conditions of rock destruction and transportation are vastly different from what they are at lower levels. It is only partially correct to discuss in terms of falling water the degradation of mountain slopes, whether tree-covered or not. Their degradation must chiefly be discussed in terms of falling rock-waste. In the lowlands stream corrasion has its maximum of destructive influence. Among the high mountains stream corrosion has a minimum of destructive influence. The analysis of high-mountain degradation deals, on the one hand, with the methods of rock-~~disin~~tegration, and, on the other hand, with the methods of carrying the resulting waste out to the lowlands. The complete analysis waits on the discovery of quantitative data. We have here another instance of the need of sharpening and extending the highland view. Yet the qualitative data already recorded leave no doubt as to which zone is the more rapidly degraded.

a) *Disintegration of rock.*—A striking proof that Anglo-Saxons have only recently begun to take the highland view appears in the

lack of a commonly used English equivalent for the German word *Felsenmeer*. Equally striking is the fact that very few physiographic textbooks even mention one of the most characteristic and widely exemplified features of alpine mountains. Frost-action is, of course, chiefly responsible for the wonderful chaos of broken rock above tree-line. The *Felsenmeer* is itself direct evidence of exceptionally rapid disintegration. At many points the blocks of the rock-chaos are in special danger of being swept away by avalanches, or of more slowly moving valleywards by the powerful thrusting action of freezing water. The development of the *Felsenmeer* means a vast increase of rock surface on which frost, changes of temperature, and all the other chief methods of weathering, and therewith destruction, can act. Below tree-line an all-mantling *Felsenmeer*, because of the forest blanket, is forbidden. Much of the broken rock below tree-line is exotic, having fallen from the treeless zone. The indigenous *Felsenmeer* below the tree-line is chiefly concentrated beneath cliffs, and is a vanishing quantity when compared with the immense rock-chaos above. Both as an evidence of incomparably more rapid frost attack above tree-line than below, and as a condition for more effective attack by agents other than frost, the *Felsenmeer* is significant.

b) *Removal of rock-waste.*—On the other hand, the streaming of weathered material down the slopes is, other things being equal, probably several times more rapid in the treeless zone than below it.

(1) The direct beat and *wash of the rain* have practically negligible effect on waste-removal below tree-line. The power of heavy rain washing the treeless zone, either in the derived form of rills or as a sheet flood, is manifest to anyone who has experienced a good shower above tree-line.

(2) During the last two field-seasons the writer has for the first time become conscious of the importance of *burrowing mammals* in preparing loose rock-waste for speedy transit to the valleys. In the western Cordillera field-mice, gophers, moles, marmots, bears, and other species are each year doing an immense geological work. There can be no exaggeration in saying that these burrowers annually turn over hundreds of thousands, if not millions, of tons of soil or disintegrated rock in either the Coast Range or the Selkirk Range of British Columbia. Such work is of relatively little importance

where mounds or fillings of snow tunnels are protected by trees overhead. It is very different above tree-line, where even the weak veneer of turf is broken in the burrowing, and where the millions of mounds or tunnel-casts are exposed to every agent of transportation.

(3) The transporting efficiency of *wind* in the treeless zone of lofty mountains has, on the whole, been more emphasized by European observers than by those of America. So far as this is the case, Europeans have come nearer to the highland view than we have in this country. The summer quiet of alpine summits of itself gives a most deceptive idea of the power of wind in the heights. During the other seasons winds of almost hurricane violence are far from uncommon, if we can generalize from the limited instrumental data so far issued from high-lying observatories. We may believe that dust, sand, and fine gravels are so rare above tree-line largely because of such winds. For obvious reasons, sand-blasting there plays no such rôle as it does in the sculpturing of rock-forms in lowland deserts; but transportation by the wind is another influence placing in strong contrast the conditions of erosion in the regions above and below tree-line.

(4) Erosion and transport through *avalanches* are enacted in both the treeless and the forested zone. In the lower zone the destruction wrought by a great avalanche may be great, but it is largely a ruin of tree-trunks. In the lower zone the avalanche paths are tolerably well fixed from year to year, sparing much the greatest part of the forested area. In the treeless zone, avalanches have generally less momentum, but they are more numerous, less localized, and therefore more likely to find and sweep down loose rock débris. Above tree-line their ruin is wholly rock-ruin. It seems safe to conclude that snow-slides are more powerful agents of degradation above tree-line than below.

(5) The general streaming and cascading of rock-waste under the direct pull of *gravity* are evidently immensely more rapid in the treeless zone than where the strong vegetation mat binds humus, soil, and bowlder to the bed-rock, though it be without perfect, ultimate success.

(6) The débris from the upper zone itself helps to protect the bed-rock of the lower zone. The very rapidity of general waste streaming above involves the slowing down of erosion below.

(7) The *chemical solution* of rock is, to be sure, probably more rapid beneath the forest-cap than it is above tree-line where the amount of vegetable acid is at a minimum. This cause may, however, be believed to do little toward counterbalancing the effect of the combined causes just enumerated. Erosion in alpine mountains takes place primarily by the removal of masses; in comparison, molecular transfer of rock material to the low grounds has but a very minor control.

Conclusion.—A review of the conditions of general degradation shows clearly its differential character above and below tree-line. Summits already reduced to the tree-line are bound henceforth to be stubborn against further erosion. Summits bearing a treeless zone are as clearly bound to continue wasting rapidly so as to tend to approach accordance of summit levels with their tree-covered neighbors. Since the glaciated zone of alpine mountains is, in general, well within the treeless zone, the special degradation due to local glaciers harmonizes with general erosion in the development of accordance.

5. *Accordance through river-spacing and gradation of slopes.*—A fifth method for the spontaneous development of summit-level accordance remains to be noted. The recent announcement and discussion of this explanation make it superfluous to present here more than the briefest analysis of the underlying ideas.[1]

Professor Shaler in America and Professor Richter in Europe have independently shown that, as mature dissection of a region under normal climatic conditions is reached, rivers of the same class tend to become nearly equally spaced. In perfect maturity the slopes of the interstream ridges are graded from top to bottom. This gradation of the slopes draining into two adjacent, nearly parallel streams flowing in the same direction, produces a comparatively even longitudinal profile of the intervening ridge. The even crest of the ridge must be more or less sympathetic with the profiles of the streams below, and, down stream, slowly attain a lower and lower

[1] Cf. R. S. Tarr, *American Geologist*, Vol. XXI (1898), p. 351; N. S. Shaler, *Bulletin of the Geological Society of America*, Vol. X (1899), p. 263; W. S. T. Smith, *Bulletin of the Department of Geology*, University of California ~~Colorado~~, Vol. II (1899), p. 155; E. Richter, *Zeitschrift des deutschen und österreichischen Alpenvereins*, Vol. XXX (1899), p. 18; W. M. Davis, *American Geologist*, Vol. XXIII (1899), p. 207.

level. Local notches or cols may be gnawed in the ridge, but all the summits must be roughly accordant, though, of course, not uniform, in altitude. Other things being equal, the more mature the dissection, the more perfect the summit-level accordance; but the principle may be applied to alpine ranges. In those ranges the actual imperfect degree of accordance may often match the imperfectly matured state of dissection.

GENERAL CONCLUSION AND SUMMARY

The form of the preceding discussion has been analytical, but its main point has been to emphasize the synthetic nature of the process of mountain sculpture. Seven different conditions of erosion *work together* to produce accordance of summit levels in an ideal alpine range undergoing its first cycle of physiographic development. Isostatic adjustment and simultaneous, differential degradation of rising blocks tend to bring about rough accordance of summit levels in the range as "originally" formed. Later differential erosion and consequent further isostatic adjustment, the influence of metamorphism and intrusion, the sculpture due to high-level glaciation, the normal existence of a high-level tree-line, and, finally, the compound process of river-spacing and slope gradation—all these may combine their effects and render more perfect the accordance of levels inherited from the early, growing period of the range.

In an actual range, as distinguished from the ideal range, all seven of these conditions may not be present; the efficiency of those that are present make the special problem of that special range.

The composite explanation of accordance must always face the alternative explanation of the peneplain theory. The latter theory involves two physiographic cycles in the history of the range, and attributes summit-level accordance to inheritance from the initial, upwarped peneplain surface of the second, present cycle. Several of the chief conditions of erosion on which the composite explanation is based, tend, of course, to preserve the accordance of levels inherited from the peneplain.

The strength of each of the two explanations is so great that a decision as to which is true for a given alpine range may need nice discrimination. Nevertheless, the profound differences between the

two theories regarding the geologic and physiographic history of the range makes the decision of primary importance. The existence of broad, little-dissected plateaus remnant from a greater plateau nearly or quite coextensive with the range having internal structures of alpine complexity, is a positive criterion favorable to the peneplain theory. From such remnant plateaus must be distinguished the elevated shelves due to high-level glacial erosion; to wind erosion; to the local control of internal structure; or to changes in conditions whereby the floors of former, high-lying basins of erosion, through deformation or through the migration ~~of~~ divides, become the summits. Peneplain remnants must further be distinguished from the common, often broad, ridge-summit formed by the meeting of two gentle slopes where the low angles of the slopes are incidental to general gradation of the mountain above tree-line. Analogous forms on a much smaller scale are never absent from the ridges in bad land topography where there is no suggestion of peneplanation.[1]

On the other hand, the remnant plateaus may not appear in the present topography of a range, and the accordance of summit altitudes may characterize peaks and serrate ridges only. Such accordance may give a comparatively even sky-line in the views from any dominating point, but the full force of the composite explanation of accordance as above outlined is directed against the reference of that even sky-line to the direct or inherited profile of an ancient, uplifted peneplain.

[1] G. K. Gilbert, *Geology of the Henry Mountains* (Washington, 1877), p. 122.

THE OSTEOLOGY OF THE *DIADECTIDAE* AND THEIR RELATIONS TO THE *CHELYDOSAURIA*

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Our present knowledge of the family *Diadectidae* has been obtained almost entirely from the writings of Cope. His work was done upon fragmentary material from the Permian beds of Texas—including, however, a few fine skulls—and was largely of a systematic character. Scattered through his many papers on this family are many brief notices and descriptions of anatomical characters, but nowhere has he given even an approximately complete description of the osteology. A summary of these brief notices would have no value beyond the historical. Suffice it to say that with his wonderful acumen he foresaw in his fragmentary material much that the more perfect material here described has made evident. For the bibliography and synonymy of the family the reader is referred to Hay's *Catalogue of the Fossil Vertebrata of North America* (Hay, 1902).

The material upon which the following description is based consists of several specimens collected by the author in the Permian beds of Texas, and now in the collection of the University of Chicago. The numbers given are the numbers of the University collection of fossil vertebrates.

The specimens consist of one nearly complete skeleton and several less perfect, as follows: (1) a skeleton lacking only the feet and free from distortion, No. 1075; (2) the anterior portion of a skull with the complete right half of the lower jaw and a portion of the left and a considerable portion of the vertebral column, No. 1076; (3) the sacrum and seven presacral vertebræ of a much larger specimen, No. 1077; (4) the major portion of a skull showing the palatal region nearly perfectly, No. 1078; (5) an imperfect skeleton showing the caudal region and some of the limb and foot bones, No. 62.

In 1896 Cope described (Cope, 1896) from the Permian of Texas two genera, which he called *Otocoelus* and *Conodectes.* These he placed in a new family of the *Cotylosauria*, the *Otocoelidae*, which he described as follows:

Posterior border of the temporal roof excavated laterally by the meatus auditus externus. Teeth present in a single row, not transversely expanded. Ribs immediately overlaid by parallel transverse derm-ossifications which form a carapace.

In the presence of the meatus auditorius this family differs entirely from the other members of the *Cotylosauria*. In the latter the vestibular space is inclosed by the lateral part of the temporal roof, and has no distal inferior bounding wall. The meatus results in the *Otocoelidae*, not merely from the excavation of the roof, but also from the excavation of the posterior border of the suspensorium. In *Conodectes* this excavation is not great, but in *Otocoelus* it is very considerable, the proximal extremity of the suspensorium having the anterior position seen in the *Loricata* and the *Testudinata*. It resembles the quadrate of the latter order in the decurvature of the proximal extremity into a descending hook, which partially bounds the meatus posteriorly.

This meatal excavation constitutes an approximation in the *Cotylosauria* to other and later orders of the *Reptilia*, where it is nearly universal. It is interesting to observe that it precedes in time the division of the roof into longitudinal bars by perforation, in the series of which the *Otocoelidae* form a part. This fact renders it probable that it is from this family that the order of the *Testudinata* has descended. . . . . In this family the slight posterior concavity of the quadrate region of the *Diadectidae* is extended forward to a great distance, and the osseous tympanum is produced farther outwards.

Later, in 1898 (Cope, 1898), he erected this family into a distinct order, the *Chelydosauria*, defined as follows:

These reptiles possessed a carapace of transverse osseous arches which extended across the back from side to side in close contact. The anterior part of the scapular arch below resembles the corresponding part of the plastron of a tortoise. The temporal roof is excavated posteriorly for the auricular meatus. The order is probably ancestral to the *Testudinata* and the *Pseudosuchia*.

In his synopsis of the orders of the *Reptilia* he describes the order as with the "scapular arch internal to the ribs; temporal region with complex roof and no longitudinal bars. A presternum; limbs ambulatory."

Cope regarded the *Otocoelidae* as the only family of the new order, but it will be seen from the following descriptions that the *Diadectidae* must be included therein. The order *Chelydosauria* is

clearly distinct from the *Cotylosauria*, the points of ordinal difference being the exposure of the quadrate to the lateral surface of the skull, the meatus auditus externus forming a third pair of openings in the skull roof, and the peculiarities of the palate cited below. The presence of a more or less well-developed carapace is perhaps definitive, but, as it occurs in many Permo-triassic reptiles, and even in *Amphibia*, *Dissorophus*, it is not fundamental. Cope included in the *Diadectidae* (Cope, 1896[1]) *Diadectes*, *Empedias*, *Chilonyx*, *Bolbodon*, and *Phanerosaurus*, which he defined as *Cotylosauria* "with hyposphen-hypantrum vertebral articulation, and teeth with robust, molariform crowns transverse to the jaws" (Cope, 1898).

Of these, *Chilonyx* and *Phanerosaurus* must be excluded from the *Chelydosauria*, as the quadrate is covered on the lateral surface by the squamosal and prosquamosal bones, and there is no external meatus perforating the skull wall; *Bolbodon* is a very uncertain form, the condition of the specimen rendering an accurate judgment impossible.

DESCRIPTION OF SPECIMEN NO. 1075

The total length of the specimen as it lies is about 1.08^m. This is nearly the natural length, as only a few inches of the tail seem missing. The animal either died in the soft mud in which it is preserved, or was entombed therein immediately after death, as there is no trace of movement by currents or the attacks of predatory animals. The fine mud penetrated all parts of the skeleton, preserving the bones in their natural position almost perfectly. Unfortunately, the distal portion of all the limbs have been lost, so that only the proximal halves of the radius and ulna, tibia, and fibula have been preserved. As shown in the photograph (Fig. 1), the head is somewhat erect. This is not entirely the accident of fossilization, for, as pointed out by Boulenger, the Cotylosaurians had no neck to speak of, and the position of the head is partly the result of its close attachment to the body. The thoracic and pelvic girdles, because of their peculiar solidity, have been preserved undisturbed, with the exception that the scapula-coracoids of the two sides have been pressed together about 1^{cm}, giving a false appearance of overlapping. The vertebræ are in the normal position above the

FIG. 1.—Photographs of the skeleton of specimen No. 1075.

FIG. 2.—Outline of the skeleton of specimen No. 1075. *cl*=clavicle, *cleit*=cleithrum, *co*=coracoid, *intc*=interclavicle, *scp*=scapula. One-fifth natural size.

girdles, but in the post-dorsal and lumbar regions the column has sagged down of its own weight, causing a break and slight displacement, vertically, of the column. One peculiar effect of the sagging down of the vertebral column is that the ribs of the thoracic region have been bent upward and backward, reversing the natural curvature so that the plates covering them seem to be on the ventral surface. The upper edges of these ribs and the dorsal edge of the scapula stand well above the tops of the neural spines. The dermal plates, which are arranged shingle-wise, were evidently firmly attached together.

The humeri and femora of both sides are in position. The humeri are extended straight backward and the femora straight forward. This position, in harmony with the undisturbed condition of the rest of the skeleton, is important as indicating the natural position of the limbs and the prone position of the animal as it crawled upon its belly.

As described above, the skull has the lower jaws so fixed that it is impossible to clear the palâte completely; but as it is entirely free from any distortion, the external form is perfectly shown. The surface of the skull, as in all of the *Diadectidae*, is very rugose, and the bones are closely anchylosed together, so that it is almost impossible to trace the sutures between the bones, such sutures as are given having been largely made out from the inferior surface of the skull in the less perfect specimens.

The skull is wide behind and narrows rapidly in the facial region, making the nose relatively thin, in this respect resembling the *Pariotichidae*. The skull proper is quite depressed, but seems much higher with the lower jaws in position, because of their great vertical extent. The upper surface of the skull is flat and of an elongate heart-shape. The parietal foramen lies near the posterior edge, and is not of such great size on the surface as to deserve the adjective "enormous" applied to it by Cope; but the edges of the foramen are beveled on the lower surface, so that the inner opening is two or three times the size of the outer. This is well shown in specimen No. 1078. There is no indication of grooves for the sensory organs.

Viewed from the side, the skull shows three openings; the exter-

nal meatus, the orbits, and the nares. The quadrate region with its opening is similar in all important particulars to the same region in specimen No. 1078. The quadrate bone is a little longer, but, as it has been impossible to free the region from all matrix, minor details are uncertain. The orbits are oval, longer than high, and look directly outward. The lower edge projects rather more than the upper, and can be seen if the skull is viewed directly from above. The antero-posterior diameter of the orbit is 0.045^{m}; the vertical diameter, 0.032^{m}. The nares are nearly circular and located at the extremity of the skull. They are placed obliquely, so that they look outward and forward. The posterior and lower walls are continued funnel-wise, the opening being in the upper anterior corner of the nostril.

The quadrate region has the greatest vertical extent of any portion of the skull, making the postorbital edge of the skull, jugal, and quadrato-jugal descend abruptly as a flange, covering the posterior portion of the jaw. The whole length of the lower edge of the skull is sharply concave, reaching its greatest height just anterior to the orbit and then descending slightly to the anterior end. The anterior end of the nose overhangs the lower jaws considerably.

Viewed from the front or rear, it is seen that the skull is much narrower than the jaws; the sides of the postorbital portion slant outward as they descend, so that the wall of the skull is oblique. The supraoccipital region is depressed between two projections of the posterior angles of the skull formed by the squamosal, or possibly even by an epiotic, though this last-mentioned bone cannot be made out. Its possible presence is inferred as possible from the condition of the *Pariotichidae*, where Cope reports its presence.

There are two small openings, the post-temporal foramina, on the posterior face of the skull near the outer edge. These open directly upon the petrosal and the upper face of the pterygoid, so that their enlargement would produce exactly the condition of the *Chelonidae* among the turtles.

The total length of the skull from the anterior end of the nose to the posterior end of the slightly projecting lower jaws is nearly 0.2^{m}. The height across the skull and lower jaws is 0.125^{m} opposite the parietal foramen.

FIG. 3a

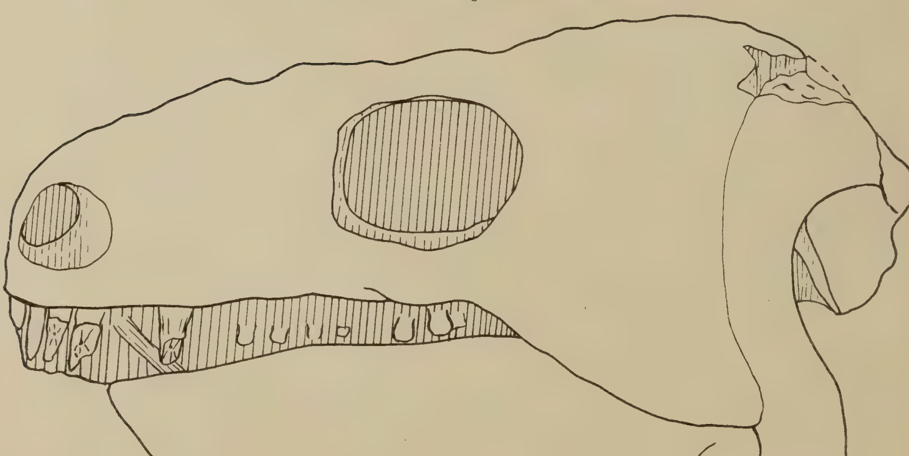

FIG. 3b

FIG. 3.—FIG. 3a, photograh of the skull of No. 1075; FIG. 3b, outline of the same skull.

In specimen No. 1078, from which the description of the palate is taken (with the exception of the vomer, which is taken from No. 1076), the skull is slightly crushed, the palate lying a little to the left of the normal position; but this has been so slight that the displacement does not amount to more than a centimeter, and the bones of the lower surface retain their connection with each other and the bones of the roof. The bones have been readily freed from a not very adherent matrix, so that the form and condition are beyond question (see photograph, Fig. 4), but the sutures

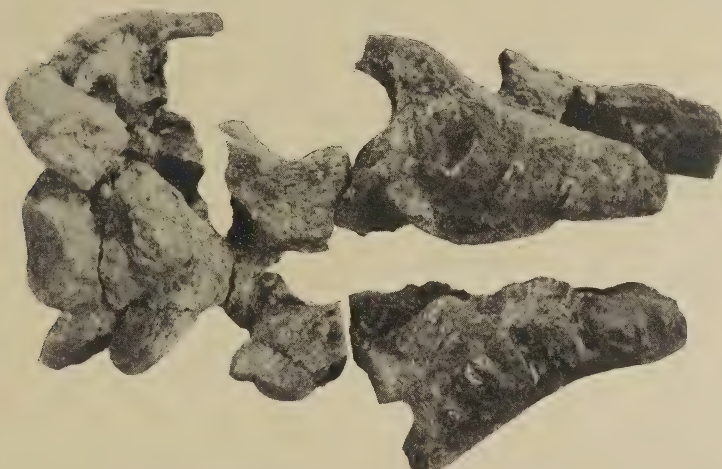

FIG. 4.—Photograph of the palate of specimen No. 1078.

are traced with difficulty. In specimen No. 1076 the skull was crushed badly, and the whole posterior portion is missing, but the lower jaws fortunately did not share in the crushing, and so show the form perfectly.[1]

[1] The matrix of specimen No. 1076 was a very hard calcareous material, which was so closely adherent to the bone that there was no line of parting where alteration due to weathering of the specimen usually marks the limits of bone and matrix. This made it almost impossible to clean the specimen with the chisel, so that recourse was had to the aid of acid, which readily attacked the matrix and the bone. As fast as a portion of the bone was freed from the matrix, it was coated with paraffin of a low melting-point, about 55° C., and the place was heated with the thin point of a blow-pipe flame until the paraffin sank into the bone, after which the attack with acid was resumed. It was found that the thin flame of the blow-pipe readily controlled the location of the paraffin, and that the heating was necessary, as simply coating the

Following is a description of the bones of the skull in detail.

The basioccipital.—The basi-occipital carries a widely oval, depressed condyle with a concave articular face. Laterally it passes into the exoccipital without appreciable sutures. It is impossible to make out the foramina.

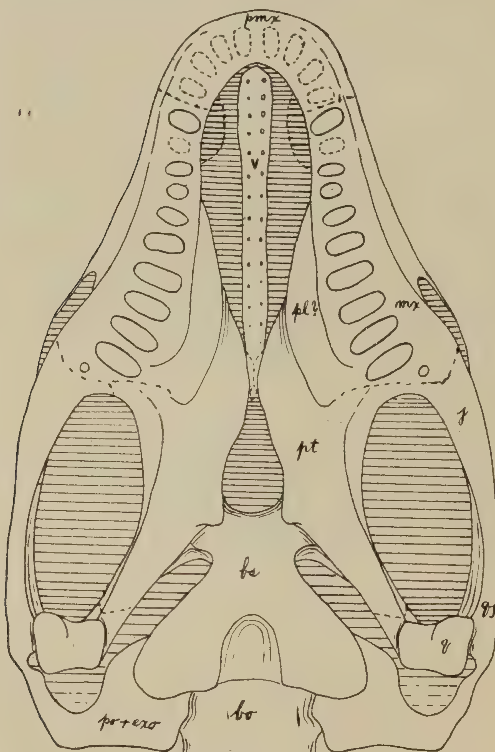

FIG. 5.—Restoration of the palatal surface of the skull from specimens Nos. 1076 and 1078.

The basisphenoid.—This bone has much the general form of the same bone in the *Pelycosauria* (Baur and Case, 1899; Case, 1905). It has the expanded posterior end where it unites with the basi-occipital, and a shallow concavity in the posterior portion of the mid-line of the lower face. The bone differs from the basisphenoid of the *Pelycosauria* in two particulars that are of great interest. (1) There is no anterior rostrum; the anterior end of the bone is rounded between the large basi-pterygoid processes, and there is no trace of any median process or of any rugosity. (2) The lower surface is not perforated by the twin foramina of the internal carotid arteries.

It is impossible to determine the limits of the bones of the brain

surface permitted the acid to work under the paraffin and damage the bone. When the specimen was cleaned from the matrix, the paraffin was readily removed by boiling the bones in water. The action of such solvents as xylol was not satisfactory in removing the paraffin.

case. Consequently no separate description can be given of the exoccipital, paroccipital, opisthotic, or petrosal. Cope reported that the opisthotic and paroccipital were separate in Empedias and Chilonyx (Cope, 1896), but I can find no trace of a separation in the specimens here described.

The quadrate.—This bone both in form and relationships is best compared with those turtles which have the quadrate open posteriorly. The rugose bones of the skull roof terminate abruptly

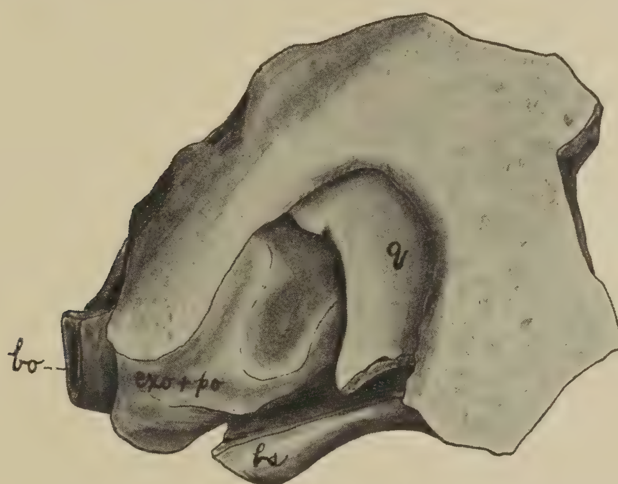

FIG. 6.—The quadrate region of specimen No. 1078. *q* = quadrate, *bs* = basisphenoid, *bo* = basioccipital, *exo* + *po* = exoccipital and paroccipital.

in the quadrate region, leaving an oval opening with its greatest axis vertical and open below. To the anterior and upper edge of this opening is attached the edge of the smooth quadrate, thus forming a conspicuous line of demarkation. The quadrate is approximately half funnel-shaped, pitching in on the upper, lower and anterior sides toward the center of the space. At this point the bone terminates by rounding in toward the center of the skull, leaving the posterior portion of the space open as the entrance of an opening to the interior of the skull. The upper part of the posterior edge of the quadrate is curved slightly downward, forming a hook. The lower portion of the quadrate is expanded into two articular faces which correspond to the articular faces of the

lower jaw. Viewed from below, the quadrate is seen to be a thin shell which is sharply convex posteriorly, the convexity forming the posterior edge described above. (The form is best appreciated by direct comparison with that of the turtles.) The outer side of this convex bone is attached to the roof bones, as described above. The inner side is attached to the pterygoid. There is a very considerable cavity between the upper portion of the quadrate and the roof of the skull anterior to it. There was no trace of a stapes preserved in the cavity of the skull posterior to the quadrate.

Cope has described the condition of the auditory region and apparatus as follows (Cope, 1886):

The brain case in the *Diadectidae* differs from that of the *Clepsydropidae* much as that of the *Varanidae* differ from those of other *Lacertilia;* that is, it is continued between the orbits, so as to inclose the olfactory lobes of the brain within osseous walls. These walls are thin, especially at the interorbital region, and in the specimen the anterior extremity is so far imperfect as to leave the form of the anterior fundus in doubt. . . . .

The conformation of the cranial walls requires preliminary notice. In the first place, the vestibule of the ear can only have been separated from the brain by a membranous septum, as is the case in the *Protonopsis horrida* (Menopoma). In clearing out the matrix no trace of osseous lamina could be detected on either side, and the edges of the huge foramen thus produced are entire, and present no broken edges. Anterior to the vestibule, the proötic bone has a small extension, terminating in a vertical border. In front of this is the huge vertical foramen through which issues the trigeminus nerve, which is even larger than that found in the *Testudinata* and *Crocodilidae.* The anterior border of this foramen is formed by the probable alisphenoid, whose posterior edge is nearly parallel with the anterior border of the proötic, sloping forward as it descends. The basicranial axis is thin at their union on the middle line below, and, thickening forward, is excavated by a rather small conical fossa. Anterior to the fossa is a smaller impressed fossa, and on either side of it each lateral wall is excavated into a shallow fossa which descends toward it. The frontoparietal fontanelle is of extraordinary size. . . . .

As already remarked, the internal wall of the vestibule is not bony, so that the cast of the brain cavity includes that of the vestibule also. On the external wall of the latter are the orifices of the semicircular canals. These are one double fossa at the superior anterior part of the wall, a second double one at the posterior superior part of the wall, and a single orifice at the inferior posterior part of the wall. The external part of the vestibule is produced upward and outward to the fenestra ovalis. The "double fossæ" above mentioned are the osseous

representatives of the membranous ampullæ at the junction of two pairs of semicircular canals.

On sawing open the periotic bones, which here form a continuous mass, the following is seen to be the direction of the semicircular canals: The superior canal is horizontal. The second canal from the posterior ampulla descends forward, and, after a course a little longer than that of the horizontal canal, turns posteriorly. The inferior canal from the anterior ampulla also descends, and, after a shorter course than the canal last mentioned, also turns backward and joins it, the two forming a single canal, which enters the vestibule by the single posterior foramen already described. The lumen of the longer perpendicular canal is much larger than that of the others. As its ampullar orifice is also the largest of all, I suppose this increased diameter to be partly normal; but it may be partly abnormal, as its walls are irregular and rough.

The fenestra ovalis is not preserved in this specimen, but can be seen in the crania of the species *Diadectus phaseolinus* and *Empedias molaris* above mentioned. The vestibule, or a diverticulum from it, is produced upward and backward, and terminates in a round os. This is clearly not a tympanic chamber, nor is it a rudimental cochlea. It does not appear to be homologous with the recessus labyrinthi, since that cavity is not perforated by the fenestra ovalis. It appears to be a promulgation outward of the vestibule and sacculus, which may be observed in a less degree in the genus *Edaphosaurus* (Cope), also from the Texas Permian formation. Here the adjacent bones are produced slightly outward, and the fenestra ovalis is closed by a large stapes similar in external form to the one I have described in the *Clepsydrops leptocephalus*. Its more intimate structure I have not yet examined.

The result of this examination into the structure of the auditory organs in the *Diadectidae* may be stated as follows: The semicircular canals have the structure common to all the Gnathostomatous *Chordata*. The internal wall of the vestibule remains unossified, as in many fishes and a few batrachians. There is no rudiment of the cochlea, but the vestibule is produced outward and upward to the fenestra ovalis, in a way unknown in any other family of the vertebrates.

The pterygoids.—These bones have the usual relations in the posterior part, but the anterior end is very different in its form and relations from that ordinarily found in the primitive reptiles. Near the middle point the pterygoids unite with the strong basi-pterygoid processes of the basisphenoid. There are strong anterior and posterior processes, but the external process which forms a buttress for the lower jaw, and is such a conspicuous feature of the skull of the *Pelycosauria* and the *Pariotichidae*, is totally absent. As this external process forms one of the chief points of attachment of the transverse bone, its absence in the skull is of considerable importance in

considering the affinities. The middle portion of the pterygoid opposite the processes of the basisphenoid is flat and even somewhat concave on the lower surface. The anterior processes extend forward and outward as flat plates to articulate with the jugal and the maxillary. The processes of the two sides diverge rapidly, so that, if they met in the middle line at all, it was only for a very short distance. The outer portion of the anterior end unites directly with the maxillary on the level of the under surface of the skull, but the inner edge rises in the skull, and its anterior part lies on the upper surface of the strong alveolar shelf or buttress of the maxillary (see description of maxillary below.) Between the anterior end of this portion of the pterygoid and the maxillary there is, seemingly, a small bone separated from the two by indistinct sutures. This I take to be the greatly degenerated transverse. The suture between it and the maxillary is marked by a large foramen.

The posterior portion of the pterygoid is vertical and joins the quadrate in the usual manner. There are no traces of teeth on the pterygoid.

The palatines.—These are very degenerate. The portion described by Cope as the palatines is evidently the anterior part of the pterygoids and the palatines he described as "maxillary ridges." They appear as ridges which originate near the middle of the maxillary bones and curve backward with them, growing gradually wider as they recede, till they terminate sharply near the posterior end of the maxillaries. At the same time the ridge curves downward and away from the maxillaries as a thin process which terminates in a sharp, rather rugose edge, much like the edge of the maxillary of a turtle after the horny sheath has been removed. This ridge is separated from the maxillary by an indistinct suture, so that it is evidently the palatine; but it occupies a most anomalous position in that it does not meet its fellow of the opposite side in the middle line, and is not articulated with the pterygoid except at the posterior end; neither does it touch the vomer. Cope mentioned teeth on what he regarded as the palatines, but I can find teeth on neither palatine nor pterygoid in two well-prepared specimens.

The transverse.—This has been described above with the pterygoid.

The vomer.—This is a single bone of considerable vertical extent which is attached anteriorly to the inner side of the premaxillaries, and posteriorly either ended freely or was touched by the anterior median portion of the pterygoids which met, or nearly met, in the middle line. Its lower surface is marked by a double ridge of sparsely set, small, conical teeth. It is impossible to trace the attachment of the upper edge of the vomer. Anterior to the parietal foramen there are, in the two skulls, the remnants of a descending median plate, but in neither can this be traced into contact with the vomer. It seems probable either that the vomer was attached to this plate by a bony connection which has been destroyed, or that there was a cartilaginous attachment between them. There is no trace of any prevomers. It is possible that in this weak palate we have the condition premised by those (Bland-Sutton, 1884; Broom, 1902) who have contended that the true vomer is the parasphenoid developed into secondary importance to supply a weakened palate.

The premaxillaries.—It is impossible in the specimens to make out the limits of these bones. Cope describes them as having short and strong spines, which ascend in the median line as far as the posterior edge of the external nares. In none is the number of teeth certain, but it does not exceed four or five. They are chisel-shaped incisors, evidently adapted to the cutting of pretty solid food.

The maxillaries.—The vertical portion of the maxillaries is very thin, but the alveolar surface is disproportionately widened to accommodate the alveoli for the great teeth. This alveolar edge, while quite wide, is not of great vertical thickness, and stands out abruptly from the side wall of the skull (formed by the vertical portion of the maxillary), as a sort of shelf upon the upper surface of which terminates the anterior end of the pterygoids and the transverse, as described above. There are eleven teeth in the portion which I take to be the maxillary. The posterior one is very small and peg-like, but the next to the last is nearly, if not quite, the largest of the series. The surfaces of the teeth are worn on the inner edge only, as described by Cope.

The palate in general.—It will be seen from the above that the palate is very aberrant and in no wise resembles the palate of the *Cotylosauria.* The bones are so closely united that it is difficult

to make out the sutures distinctly in all cases. Among the peculiarities of the palate are the following: There are no buttresses for the lower jaw on the outer portion of the pterygoids. The pterygoids end anteriorly on the upper surface of the maxillary, with a very degenerate transverse separating them only partly. The pterygoids touch the vomer only at the extreme posterior end, if at all. Because the palatines do not extend inward to meet in the middle line, there is a great median vacuity which is divided by the vomer. Into this vacuity the anterior nares open directly (Figs. 4 and 5).

The lower surface of the skull roof is marked by two descending processes which originate just posterior to the pineal foramen and extend forward well anterior to it. The lower ends of the processes are not preserved, but they are in the position of the descending plates of the parietal bones found in the turtles. Cope describes them as alisphenoids and mentions their extending forward to carry the brain case between the orbits. The upper ends of the plates are fused with the lower surface of the parietals, so that they cannot be reckoned as epi-pterygoids. Immediately in front of these two processes there is a wide process on the lower surface of the skull in the median line, so that it in some measure closes the anterior end of the space between the paired processes. This median process is continued forward and downward as a thin plate which lies immediately above the vomer, but in no specimen of the collection can be shown to connect with it. Possibly the two were united by cartilage. I take this median plate to be the forward and upward continuation of the basi-cranial axis, the ethmoid.

The lower jaw.—Except for the teeth, the lower jaw is peculiarly testudinate in appearance. The anterior portion has a relatively great height, due largely to the dentary; but there is a very inconspicuous coronoid process. The bones, like those of the upper portion of the skull, are so closely united that the sutures are almost unrecognizable.

The inner surface is marked by an enormous opening into the Meckelian groove. This opening is separated from one equally large on the superior surface of the posterior portion of the bone by a narrow bridge, presumably formed by the splenial. The cavity of the Meckelian groove is large, so that the jaw is practically a shell

with the upper portion thickened to receive the alveoli of the great teeth. The teeth are set in shallow alveoli, which do not reach to the outer side of the bone, but are separated from it by a deep groove,

FIG. 7.—Photograph of the inner surface of the right half of the lower jaw of specimen No. 1076.

the outer edge of which is formed by a narrow elevated edge of the dentary. In the anterior end of the jaw the teeth reach the outer

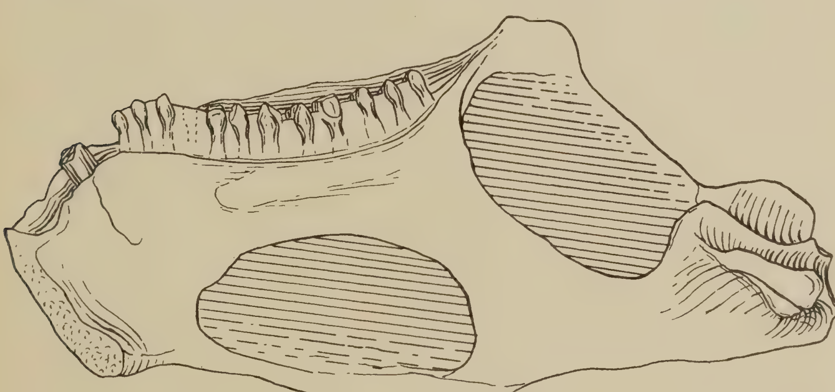

FIG. 8.—Outline of jaw shown in Fig. 7. One-third natural size.

surface. The anterior portion of the jaw descends slightly to the symphasis.

The posterior portion of the jaw descends rapidly from the coronoid; the articular surface is not above the middle half of the jaw. The articulation consists of two deep cotyli elongated in the anterior

direction and deeply concave from side to side. The shape is best shown in Figs. 8 and 9. The outer of the two cotyli is the larger, and is nearly twice as wide as the inner. It is impossible to distinguish the bones of this region as separate elements.

The outer face of the jaw is rugose, and near the anterior end of specimen No. 1076 it is marked by a depression evidently for the attachment of powerful muscles. This depression at first seems due to crushing, but there is no evidence of breaking, and the same thing occurs on both jaws. There is no such depression in the jaws of specimen No. 1075. The symphasis of the jaws was sutural, narrow, and nearly vertical.

There are eleven of the wide molariform teeth, and one empty alveolus in the posterior portion of the jaw. Anterior to these there is a single large incisor tooth, and the empty alveoli for four more, so that, if there was a small peg-like tooth at the posterior end corresponding to the small tooth at the end of the maxillary series, there were in all seventeen or eighteen teeth. The whole series of teeth is slightly concave from before backward and convex toward the middle line. The teeth are worn on the outer half only, to correspond with the wear of the inner side of the maxillary teeth. The posterior teeth are the wider, and after the posterior eight they rapidly narrow toward the front.

The shoulder girdle (the description of the shoulder and pelvic girdles is taken from specimen No. 1075).—The shoulder girdle consists of the interclavicle, clavicles, scapulæ, coracoids, precoracoids, and cleithra. The scapula, coracoids, and precoracoids are closely united. This, with the condition of the bones, makes it impossible to trace the exact form of the separate elements. The form of the three united bones is very similar to the scapula-coracoid figured by Broili as belonging to *Naosaurus* (Broili, 1904, Figs. 5, 5*a*, Plate XIII). This determination of the bones is erroneous, as it is very far from the condition of the *Pelycosauria* and closely approaches that of the *Diadectidae* here figured. The scapula is rather elongate and narrow vertically. Its posterior end terminates in a rather sharp point. The edge of the articular cotylus is very prominent, and the face looks backward rather than outward. In the *Pelycosauria* there is a foramen which penetrates the shaft of the scapula on the

outer side just posterior to the articular face, and passes forward and inward to open on the inner face of the bone in the bottom of a pit which also receives the opening of the coracoid foramen. In this specimen the foramen opens on the lower edge of the shaft and is almost within the articular space. Its position on the inner face cannot be given.

The line between the coracoid and precoracoid cannot be distinguished. The two bones extend forward and inward as flat plates which terminate in a straight anterior-posterior line medially. The two plates of the opposite side normally joined in a symphasis, but the two sides of the shoulder girdle have been pressed together, causing the two plates to overlap each other to the extent of about 1^{cm}. In addition to reaching inward to the middle line, the coracoid is extended so far backward that its posterior edge is nearly on a line with the posterior end of the interclavicle. There is a prominent articular face on the coracoid, opposed to the face on the scapula and arranged to permit the same sort of an oblique articulation with the head of the humerus as occurs in the *Pelycosauria*. Between the two articular faces originates a deep elongate pit which runs about 2^{cm} towards the precoracoid. It occupies much the same position as the cavity between the scapula and precoracoid figured in *Pareiasaurus* by Seeley and called by Furbringer the *Incisura (Fenestra ?) coraco-scapularis*, but it does not open through the bone. I cannot imagine the meaning of this pit, unless it is a scar formed on the bottom of the humeral cotylus by the attachment of a very strong ligament, such as sometimes occurs in the acetabulum. The coracoid foramen cannot be made out. In the *Pelycosauria* it opens at the base of the scapular portion of the humeral face, but I cannot find it there in this specimen. However, it was undoubtedly present.

FIG. 9.—Rear view of jaw shown in Figs. 7 and 8. Natural size.

The inward and posterior extension of the coracoids and pre-

coracoids, and their union in the median line, made a strong ventral covering to the thoracic region not unlike that of *Procolophon.*

The cleithrum.—The posterior portion of the upper edge of the scapula is bordered by a short bone which is wider posteriorly and narrows to a point anteriorly. It is anchylosed to the scapula, but posteriorly the division is marked by a deep groove. The form is best seen in Fig. 2. Its anterior edge touches, but does not articulate with, the scapula. This bone is evidently the cleithrum. It has much the appearance of the same bone in *Pareiasaurus* and the scapula figured by Broili, mentioned above, and is in about the same stage of degeneration.

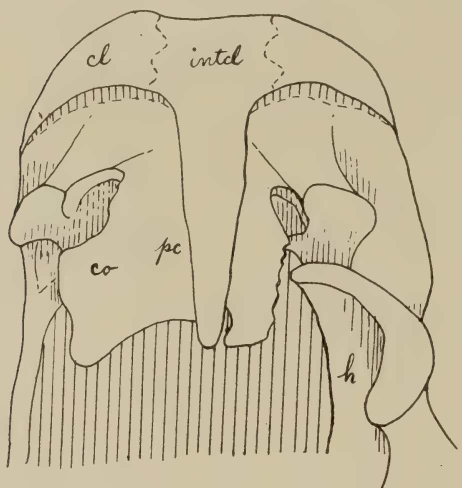

FIG. 10.—Ventral view of the shoulder girdle of No. 1075. *cl* = clavicle, *intcl* = interclavicle, *co* = coracoid, *pc* = precoracoid, *h* = humerus. One-half natural size.

The clavicles.—The clavicles do not meet in the middle line, but are separated by the interclavicle, with which they are closely articulated by strong sutural processes. Cope speaks of the symphasis of the clavicles behind the interclavicle, but this is an impossibility in the *Diadectidae,* as will be seen from the description and figures of the interclavicle. Viewed from above, the clavicles plus interclavicle have the form of a narrow horseshoe, the anterior end of the clavicles being wide and narrowing gradually to a point at about the posterior one-fourth of the scapula. The upper surface of the clavicles is quite flat. Viewed from the side, the anterior portion of the clavicles is broad, but rapidly narrows to an edge which disappears behind the cleithrum.

The interclavicle.—This bone is somewhat T-shaped. Its form is best seen in Fig. 10. The middle of the anterior end is slightly concave and rounded. Laterally the wing-like sides unite by strong

interlocking sutures with clavicles. The posterior process is continued backward, gradually narrowing to a point. Fig. 11 is a photograph of the interclavicle of a larger specimen (No. 1079), but shows the character of the surface and the connections with the clavicles.

The vertebræ. — Specimen No. 1077 consists of the two sacral vertebræ and seven presacrals. They are much larger than any of the specimens in which the skull is preserved. The whole series is characterized by the great width of the neural arch compared with the antero-posterior diameter. The neural spines are short and stout; the centrum is simple and deeply biconcave; there are no intercentra preserved. The anterior one of the seven presacrals is free from the others and very perfect, so that I have selected it as characteristic of a mid- or posterior dorsal. The anterior and posterior faces of the centrum are round and deeply concave, and it is perforated by the notochordal foramen. The lower edge of the centrum is slightly concave from before backward, and is without any median keel. The neural arch is anchylosed to the centrum, and there is no trace of the suture. As shown in Figs. 12–14, the anterior and posterior zygapophyses are far above the neural canal. The articular faces are almost flat, but are inclined slightly toward the median line, so that the anterior ones look inward as well as upward, and the posterior ones outward as well as downward. The posterior face is considerably higher than the anterior. Both faces are

FIG. 11.—Ventral surface of an interclavicle of a larger specimen than No. 1075—No. 1079.

marked by faint rugose ridges concentric around the inner end. Between the two faces and on a level with the posterior the transverse process for the rib originates and extends forward and downward until the lower end is just above the upper third of the anterior face of the centrum and directly below the anterior zygapophysis. On the anterior face of the vertebræ the inner ends of the articular faces of the zygapophyses are continued inward and downward as strong processes which bear on their inner ends the faces of the hyposphene inclined sharply inward and downward. These faces are shorter than the zygapophysial faces, but are fully as deep and as well developed. They form a striking feature of the vertebræ. Between the inner ends of the zygapophysial faces is a deep nearly round pit with a rugose bottom. It is directly above the neural canal, from which it is separated on the face of the vertebræ by a wide V-shaped partition. The posterior face of the inner ends of the zygapophyses are continued downward and inward as strong ridges which separate a deep triangular pit above, in the median line, from the hypantrum faces below. This triangular pit corresponds to the rounded pit on the anterior face, and the two evidently afforded attachment to a very stout ligament which bound adjacent vertebræ together. (Compare Cope's idea of the external form and habits given below.) The upper end of the neural spine is divided antero-posteriorly by a shallow, V-shaped channel. The anterior and posterior edges of the spine are drawn out into sharp edges, giving the whole a diamond-shaped section.

FIG. 12.—Anterior view of the seventh presacral vertebra of specimen No. 1077, showing hyposphene and pit above the neural canal.

This vertebra is undistorted, so that the following measurements are characteristic:

Total height from the lower edge of the anterior face to the apex of the spine	0.143^{m}
Width across the anterior zygapophyses - - - - -	0.111
Width across the transverse processes - - - - - -	0.122
Antero-posterior diameter across the zygapophyses - - -	0.066
Antero-posterior diameter of the centrum, approximate - - -	0.036

The six presacral vertebræ following the one described above do not differ from it in many particulars. The centra become slightly

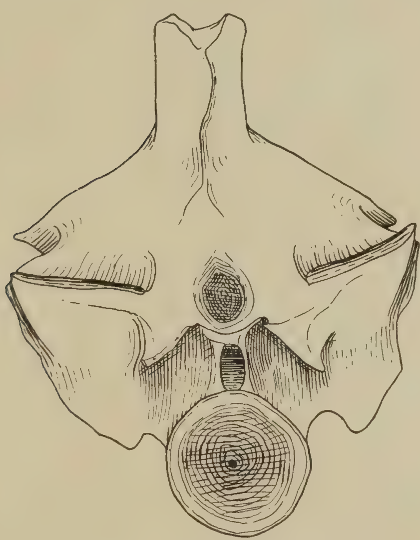

FIG. 13.—Outline of vertebræ shown in Fig. 12. One-half natural size.

FIG. 14.—Lateral view of vertebra shown in Figs. 12 and 13. One-half natural size.

shorter in the posterior ones, the first presacral is the shortest, and the dorsal spines become irregularly larger and heavier. The main difference is in the size and position of the transverse processes. These become progressively shorter, and with less well-defined articular faces for the ribs, as they approach the sacrum. The shortening is accomplished at the upper end only. The lower edge of the process, except in the last two, remains opposite the upper fourth of the centrum, but the upper end gradually drops from a

point opposite a line connecting the zygapophysial faces to a point opposite the neural canal. The articular faces of all except the last two retain the same slant forward and downward as described

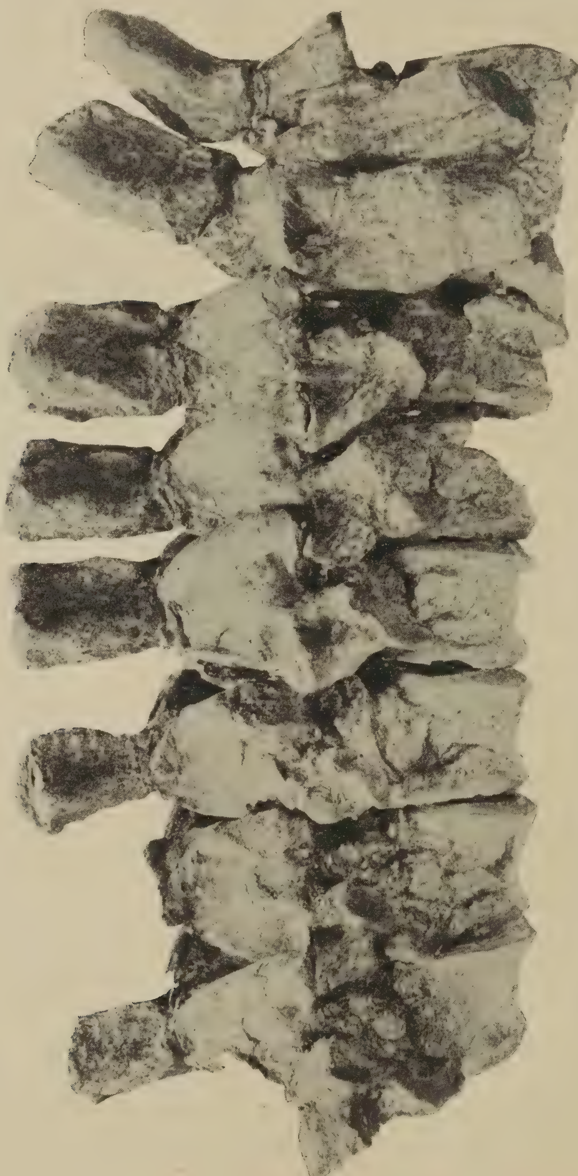

Fig. 15.—Photograph of the sacrum and six presacral vertebræ of specimen No. 1077.

in the seventh presacral. The last two vertebræ have the transverse processes much smaller than the preceding ones, and the upper end is much farther to the rear; the articular face is more nearly horizontal. The articular faces for the ribs are very poorly developed, in strong contrast with the condition of the more anterior vertebræ; these two may be recognized as lumbars.

The two sacrals present a strong contrast to the presacrals. They are closely anchylosed together, so that not only are the centra joined,

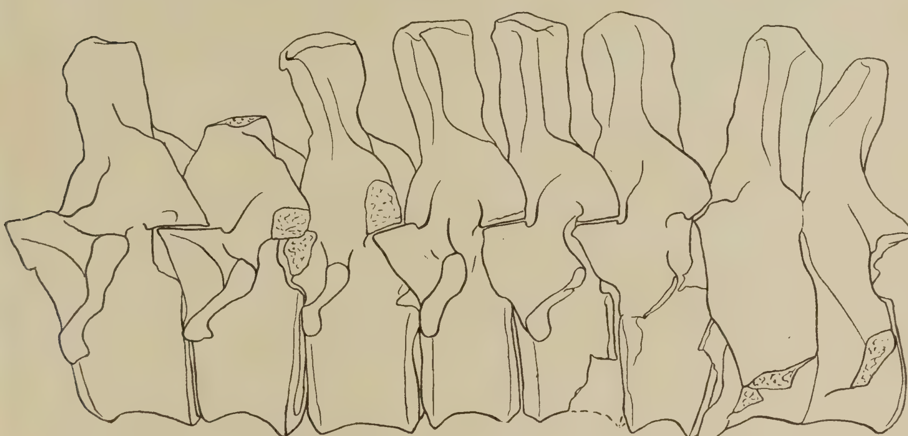

FIG. 16.—Outline of vertebræ shown in Fig. 15. One-half natural size.

but the zygapophysial articulations have disappeared and the processes pass into one another without suture. Both vertebræ present well-developed articular zygapophysial faces to the adjacent lumbar and caudal vertebræ. The transverse process of the first sacral is very wide, originating from the bases of the zygapophysial processes and maintaining a width equal to the anterior-posterior diameter of the centrum. The articular face for the rib is completely horizontal, but the rib is anchylosed to the process, so the face is traceable by a suture line only. The process and rib extend almost straight downward and articulate with the anterior end of the ilium (shown by specimen No. 1075). The transverse process of the second sacral is very much narrower and more rounded than the first, but extends downward, and is anchylosed with a sacral rib as in the first. The neural spine of the first sacral is larger than the

lumbar spines and is inclined sharply to the rear, leaving a considerable space between it and the last lumbar. The second sacral has a smaller and more slender spine than the first, but there is the same inclination to the rear. The neural arch, seen from above, is much narrower, and the sides are not rounded out into the almost hemispherical form characteristic of the presacrals. In fact, the sides of the neural arch are almost concave. The centra are abruptly longer than the last lumbar, and the bases of the centra are closely united. There is no intercentrum. Attached to the anterior edge of the first sacral is an intercentrum which underlies the space between the last lumbar and the first sacral. This is the only intercentrum preserved in the specimen. The total length of

FIG. 17.—Superior view of the posterior five vertebræ shown in Fig. 16.

the sacrum and six presacrals is 0.33^{m}. The average height of the vertebræ is 0.165^{m}.

The vertebræ of specimen No. 1076 consists of five anterior dorsals in series, and, after a break, six more in series connected with the two sacrals, making thirteen in all. The vertebræ are smaller, but present no points of generic difference from specimen No. 1077 and are less well preserved. The five anterior vertebræ are all of the same type, and the description given of the vertebræ in No. 1077 is strictly applicable. In the middle of the series the heads of two or three ribs are preserved, and show that there was no division into a capitulum and tuberculum, nor any approach to such a division. There are no intercentra preserved. In the posterior series the transverse processes of the vertebræ show the same series of changes as described in No. 1077, and the sacrals confirm the observations made on that specimen.

In specimen No. 1075 the entire vertebral column is preserved, with the exception of a few terminal caudals. The vertebræ cannot be freed from the hard matrix sufficiently to warrant a complete description, but enough can be seen to show that they conform very closely to the descriptions given above of the other specimens, and that from anterior dorsals to lumbars there is very little change in form. The anterior cervicals are preserved, but the matrix at this point is exceptionally hard and is fissile, so that it has been impossible to make out this important region. A short cervical rib has been uncovered on one side. Although the anterior caudals of this specimen have not been made out, another specimen in the collection, No. 62, shows the caudal region. This shows that the tail was short, and that the posterior caudals were supplied with strong chevrons pointed sharply backward (Case, 1903; Fig. 10).

Intercentra are preserved in all parts of the column exposed, i. e., from the cervical to the lumbar. They are thin plates, only slightly curved, so that they extend only a short way up on the sides of the centra. They are broad antero-posteriorly. The intercentra simply underlay the point of contact of two centra and were not closely attached.

The ribs.—There were evidently ribs on all the vertebræ. The anterior cervicals are covered with matrix, but on one side a rib of about 2^{cm} has been exposed which was attached to either the second or the third cervical. On the third or fourth vertebra the ribs have reached a considerable length, and by the fourth or fifth the ribs have reached the greatest length of the body. As far back as the ninth vertebra the ribs have suffered the distortion described above, so that they are bent sharply backward and upward. In the posterior portion of the column the ribs curve sharply to the rear and gradually shorten, so that on the posterior dorsals and the lumbars they are quite short and slender. The dorsal plates overlie the ribs of the anterior vertebræ only. But four plates can be counted in series, but there were probably one or two anterior to them. In the description of specimen No. 62, mentioned above, the author described for the first time the occurrence of the plates in the *Diadectidae*. In that specimen they occurred as a fragment, but show the presence of at least five. In the anterior plates the ribs seem to be short and fused

to the under surface of the plates as in the turtles (this point is somewhat uncertain), but in the posterior plates the ribs are separate. The anterior plate is the broader and larger; the following ones diminish rapidly in size, and do not reach nearly to the end of the rib. It is evident that the plates did not cover the back, but lay on the sides of the body, with a wide interspace over the neural spines. In this as in other respects the carapace is much less perfect than in the *Otocoelidae.* Cope describes the shoulder girdle of the *Otocoelidae* as lying within the ribs. This does not occur in the *Diadectidae.* The plates lie between the scapula and the ribs. So peculiar is their position that at first glimpse they have a strong suggestion of beginning plastral elements.

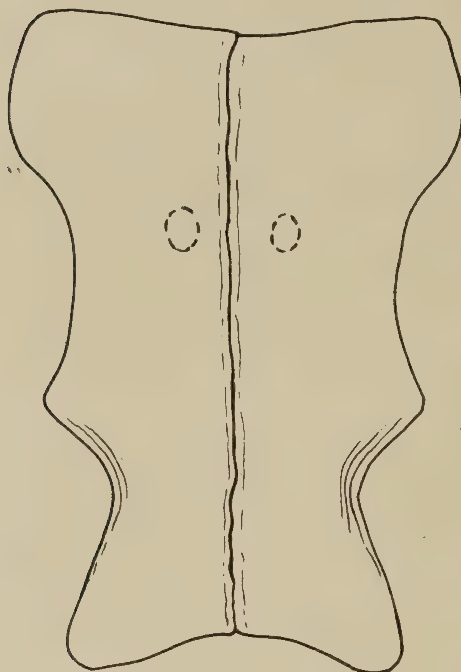

FIG. 18.—Outline of the lower surface of the pelvis of specimen No. 1075. One-half natural size.

The pelvis.—The pelvis shows the same adaptation to the depressed form of body as the shoulder girdle. The pubis and ischium are flat and plate-like, and the lower surface of the pelvis formed by the four bones is horizontal. There is no trace of the pubo-ischiadic suture, and the bones of the two sides meet in a straight symphysis, which is marked by an elevated ridge. The ilium stands vertically at a right angle to the other bones. (See Figs. 2 and 18.)

The ilium.—The crest of the ilium is nearly straight on the upper edge, the anterior end is rounded, and the posterior end is continued backward into a straight point. The lower portion forms the upper part of the acetabulum. The anterior edge of the lower parts slants forward and downward to join the pubis.

The pubis.—This is wide anteriorly and narrows slightly anterior to the acetabulum. The pubic foramen is near the middle of the bone. The anterior edge is nearly straight, but is slightly inclined backward toward the middle line, so the edge is somewhat notched.

The ischium.—This is narrower than the pubis and is sharply contracted posterior to the acetabulum, which has on this bone a

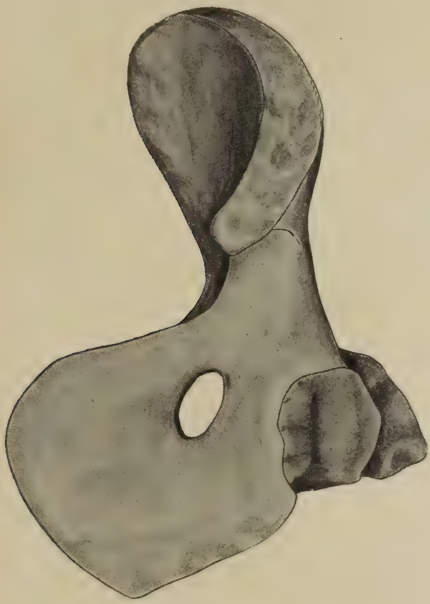

FIG. 19

FIG. 20

FIG. 19.—Anterior view of humerus of specimen No. 1075. One-half natural size.

FIG. 20.—Anterior, lower view of femur of specimen No. 1075. One-half natural size.

prominent rim. The posterior edge of the pelvis formed by the two ischia is even more deeply notched than the anterior.

The humerus.—This is a relatively short and wide bone, but of the same general type as occurs in all of the *Cotylosauria*. There is a very strong radial process reaching to near the middle of the shaft, and a large entepicondylar foramen near the middle of the lower end. The process for the head of the radius is broken away, but the entepicondylar process is exceptionally wide and large. The

total length of the bone is 0.157^{m}. The width of the lower end is 0.102^{m}.

The femur.—The femur is of a very simple type. There is no distinct head, and there is the usual concavity on the anterior face near the proximal end. There is a low but distinct ridge connecting the upper and lower ends on the anterior (inferior) face which crosses the bone somewhat obliquely. The distal condyles are almost entirely on the anterior face. The length of the bone is 0.150^{m}.

Only the proximal ends of the bones of the forelegs remain, but these, with the described bones of specimen No. 62, show that they were proportionately short and stout. In the description of specimen No. 62 figures were given showing that the phalanges were short, and that the foot must have been short and strong, with stout nails or claws, perhaps fitted for digging. Unfortunately, no attempt can be made to give the phalangeal formula.

Form and habits.—Cope makes the following suggestions regarding the *Diadectidae:*

> There is some reason to believe that the Diadectes relied exclusively upon the pineal eye for the sense of sight. The species of the family were subterranean in their habits, since their humeri indicate great fossorial powers, resembling those of the existing monotremes and even the moles. The vertebræ are locked together with hyposphen beside the usual articulations, and the arches of the neural canal form an uninterrupted roof from the skull to the tail, of extraordinary thickness and strength. That the species are not aquatic is rendered probable by the fact that the orbits do not look upward. Their superior borders are, on the contrary, prominent and straight. Add to this fact the apparent absence of optic foramina, and the probability that the *Diadectidae* were blind and subterranean in their habits becomes still stronger.

There seems little doubt that the points made by Cope are in the main correct. The animals were undoubtedly flat of body and strong of limb in regard to their digging powers. It may be doubted, however, if there is sufficient evidence to warrant the suggestion that they were blind. If they resembled the turtles as much as seems probable, it is very possible that the optic nerves escaped from the brain case in the same way without any special foramen.

It will be seen from the above description that the family *Diadectidae* must be removed from the *Cotylosauria* and placed in the order *Chelydosauria*. It also supports in a most striking manner the

statement made by Cope that the last order was ancestral to the turtles. It is not assumed that the *Diadectidae* are the direct ancestors of the turtles, nor can this statement be made in regard to any of the *Chelydosauria;* for in none is there any beginning of the development of a plastron, and only an incipient carapace, which cannot be regarded as determinative, as it also occurs in an amphibian *Dissorophus*, of the same beds. The only features of the body skeleton prophetic of the turtles are the beginning of the carapace and the number of presacral vertebræ, which is eighteen—a number which also occurs in many of the *Cotylosauria*. It is in the skull that the testudinate affinities appear. For convenience of discussion, the seven most important points are listed below:

1. The form and relations of the quadrate.
2. The degenerate palate and the disappearing transverse bone.
3. The absence of teeth on the pterygoids and palatines.
4. The absence of a parasphenoid process on the basisphenoid bone.
5. The absence of prevomers and the presence of an anteriorly placed single vomer (parasphenoid).
6. The method of entrance of the internal carotid arteries into the skull.
7. The presence of paired descending plates from the skull roof anterior to the brain cavity.

These will be discussed in order.

1. The form and relations of the quadrate. In the order *Cotylosauria* there are, as in the *Stegocephalia*, but five openings in the skull roof—the nostrils, the orbits, and the pineal foramen. The quadrate region is covered by dermal bones, so that the quadrate bone is seen only from behind or below to any extent. In the *Chelydosauria*, as described above, the quadrate appears on the side of the skull, and forms a portion of the side wall, surrounding an opening, the meatus auditus externus; the meati of the two sides forming a third pair of openings to the interior of the skull. As pointed out in the description, the quadrate bears exactly the relations to the bones of the roof and lower portion of the skull that the same bone bears in the turtles, and there is a suggestion of an overhanging hook on the posterior edge, indicating the beginning

of a closure of the bone to form a complete tympanic ring. But we know that there are many turtles in which the tympanic is open behind. Baur gives the following list: *Amphichelydia*, *Dermatemydidae*, *Staurotypidae*, *Kinosternidae*, *Toxochelydae*, *Platysternidae*, *Emydidae*, and *Adelochelys*.

2. The degenerate palate and the disappearing transverse. It is evident that the palate is very different from that of the *Cotylosauria* and from any of the more primitive orders of reptiles, as *Proterosauria*, *Proganosauria*, *Rhyncocephalia*, etc. There is no anterior rostrum (presphenoid auct.) on the basisphenoid; there are no paired prevomers; the palatines and transverse are degenerate; there is no descending buttress on the external process of the pterygoids for the lower jaw. The condition of the anterior rostrum of the basisphenoid and the prevomers is discussed below. It is apparent that the palate is in process of change toward a new type. It may well be that the *Diadectidae* show an extremely degenerate example of this change, and that the more successful line showed no such violent differences from the parent form at any stage. The ridge-like form of the palatines on the edge of the maxillaries speak of their extension toward the middle line to meet a median element extending far posteriorly—an element which already exists, but from which they are separated by the long antero-posterior vacuities of the palate. The firm attachment of the pterygoids to the maxillaries is indicative of the final disappearance of the transverse, one of the most characteristic features of the Chelonian palate.

3. The absence of teeth on the pterygoids and palatines. In all other forms of the *Cotylosauria* there are teeth on the pterygoids or palatines, or both. Two specimens show that they are absent in the *Diadectidae*.

4. The absence of a parasphenoid process on the basisphenoid bone. If we accept without argument or review the position taken by Broom, that the true vomer is the parasphenoid in a new position and with a new function, and that the paired elements of the reptilian skull usually called vomers, are really distinct elements, then the identification of the parasphenoid in the skull becomes of extreme morphological importance. It has been shown by Howse and Swinnerton (Howse and Swinnerton, 1901) and Siebenrock (Sieben-

rock, 1897) that in *Sphenodon* the rostrum of the basisphenoid is the parasphenoid; the basisphenoid with its anterior rostrum develops from three centers—two posterior, in the cartilage of the skull axis, and one anterior, in the lining membrane of the floor of the pituitary space. The same observation has been reported and confirmed in the development of the Lacertilian skull. It is evident, then, that the rostrum of the basisphenoid is the remnant of the parasphenoid in the reptiles. (It is common to refer to this rostrum as the presphenoid—a distinct error, as the presphenoid is a continuation of the cartilaginous basicranial axis, and not a membrane bone.)

There is no such rostrum developed in the turtles. I am aware that Parker reported (Parker and Bettany, 1877, p. 214) that the basisphenoid of the turtle is developed from three centers, as in the *Lacertilia*, but this is denied by Siebenrock (Siebenrock, 1897), who also cites Rathke (Rathke, 1848), as follows:

> Dass sich das Basisphenoideum bei den Schildkröten nur in einfacher Zahl bildet denn selbst bei denn reifern Embryonen, konnte Rathke nicht das geringste Zeichen anfinden, dass es ursprünglich aus einem hinteren und vordern Stücke bestanden hatte.

Siebenrock further explains the apparent rostrum of the turtles by the elongation and approximation of the trabeculae inferiores (Siebenrock, 1897, p. 18).

In an examination of the *Reptilia* I find the following condition: The parasphenoid is absent as a rostrum of the basisphenoid in the *Chelydosauria*, *Testudinata*, *Cotylosauria partim* (*Telerpeton*, *Pareiasaurius* (?), *Procolophon*). It is present in the *Ichthyopterygia*, *Sauropterygia*, *Squamata*, *Theropodous Dinosaurs* (*Diplodocus*), *Cotylosauria partim* (*Pariotichidae*, *Labidosaurus*).

It now becomes necessary to discuss this point in connection with the fifth point:

5. The absence of the prevomers and the presence of an anteriorly placed single vomer. In the forms where there is a rostrum on the basisphenoid there are always paired prevomers, but where this rostrum is not developed there is a single, anteriorly placed vomer and no prevomers.

Broom has shown (Broom, 1904) that the median vomer of the turtles is probably the parasphenoid. The condition of the vomer of

the *Diadectidae* indicates that it may well be the parasphenoid detached from the basisphenoid and placed in an interior position, retaining its connection with the basisphenoid by extension of the cartilaginous basicranial axis, if at all. Perhaps the median ossified plate described as descending from the anterior part of the skull roof is an ossification of the ethmoid complex, and aids in the support of the vomer. The list given above shows that the parasphenoid rostrum of the basisphenoid is not a constant feature even in well-defined *Cotylosaurians*.

6. The method of entrance of the internal carotid arteries into the brain cavity. In the *Rhynchocephalia* and *Squamata* the carotid arteries divide beneath the skull floor, and the internal carotids pass through the basisphenoid from below, leaving a pair of foramina which are very constant and noticeable features. In many of the turtles the carotids pass into the skull through a foramen posterior to the quadrate, and then divide into an internal and external carotid. The internal carotids enter the basisphenoid through the side of the bone, and then pass out of the top, leaving no foramina on the lower surface. This character is not constant for all turtles. In some the internal carotids enter the pterygoid, or the foramen is in the suture between the basisphenoid and pterygoid.

I find foramina on the lower surface of the basisphenoid in the *Rhynchocephalia*, *Squamata*, and probably *Dinosauria*. In the *Testudinata* (*partim*), *Chelydosauria*, *Crocodilia*, there are no foramina on the lower side of the basisphenoid.

7. The presence of paired descending plates from the skull roof anterior to the brain cavity. As no trace of an epi-pterygoid was found, the paired plates descending from the lower surface of the parietals is strongly prophetic of the plates in the turtles. They have the same position and, apparently, the same relation to the pterygoids below and the foramen for the fifth nerve.

Opposed to the Testudinate affinities is the absence of any plastral elements, even abdominal ribs, and proscapular process of the shoulder girdle.

In just the characters in which the *Chelydosauria* (*Otocoelidae*, *Diadectidae*) approach the turtles they are distinct from the *Cotylosauria* (*Pareiasauridae* and *Pariotichidae*), and so it seems very probable that we have in the *Diadectidae* forms very closely related

to the ancestral stem of the turtles which tell us much regarding the development of the *Testudinata* directly from the *Cotylosauria.*

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SOME INSTANCES OF MODERATE GLACIAL EROSION[1]

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Instances of marked glacial erosion have in recent years been reported from many sections, but very little has been written regarding evidences of moderate glacial erosion. In several widely separated localities I have found definite proof of moderate ice-erosion, which, in view of the growing tendency to assign to ice great erosive power, seems worthy of statement at the present time. These instances will be considered one by one.

SOUTHERN CENTRAL NEW YORK

South of the Finger Lakes is a plateau upland which was completely overridden by ice of the Wisconsin stage. Across this upland extends a series of moraines marking a prolonged halt of the receding ice. South of the recessional morainic belt there are numerous evidences of moderate glacial erosion, and no proof that the topography was perceptibly modified by ice-erosion, although during the time that the ice-front stood at the terminal moraine, about 50 miles farther south in Pennsylvania, the highest hills were completely covered.

The most important evidence of moderate glacial erosion in this plateau region is supplied by the presence, in numerous localities, of residually decayed materials in place, not only on lee slopes, but on hilltops and on the stoss sides of hills. The decayed material varies from discolored and disintegrated shale fragments beneath sandstone caps to fine-grained residual clay resulting from the decay of the shale (Fig. 1). In such cases the sandstone cap layers are cracked and broken, and the decayed shale is in some instances three feet below

[1] This paper was presented before the first meeting of the Association of American Geographers at Philadelphia. The facts relating to New York were discovered while working for the U. S. Geological Survey, and are published by permission of the director.

the surface. That this clay is not the result of postglacial decay is proved by the fact that in some places the striæ on the sandstone caps are not yet destroyed by weathering.

It is only occasionally that cuts fresh enough to reveal the actual condition are found, but it is evident in the field that unremoved products of rock decay are widespread. This is proved by the

FIG. 1.—Decayed shale between sandstone layers, one mile east of Berkshire, N. Y., on Harford (U. S. Geological Survey) Topographic Sheet. The shale shows spheroidal weathering and between the nodules is residual clay.

presence in the fields of abundant slabs of sandstone, many of which are profoundly decayed, with a deep rim of oxidized rock, and with fossils completely weathered out. Very often plowing has encountered weathered sandstone caps under the thin upland soil, and, by upturning the slabs, has transformed the fields to such stony areas that the sandstone fragments cover fully 50 per cent. of the area. The till of this region is made up largely of local sandstone fragments, mixed with residually decayed clay and a relatively small proportion of foreign stones and rock flour, making a very peculiar soil. The

Soils Bureau of the U. S. Agricultural Department recognized this peculiarity, and in mapping the soils of the Elmira Sheet correlated the upland till with a type of residual soil under the name of Hagerstown shale loam.

This residually decayed material is not confined to a small area, but has been found in the mapping of glacial deposits on eight topographic sheets, and it is certain that throughout this area there has been such slight glacial erosion that in many places, even where conditions seem favorable, the residually decayed products were not removed by the Wisconsin ice-sheet. Whether this is preglacial or interglacial decay is not certain; but so far no facts have been discovered in this region to prove an earlier ice-advance.

It is true that this is a region in which the length of ice-occupation was relatively brief, and in which the hilly topography was opposed to vigorous ice-action. But even under these conditions it is a significant fact that ice could have moved over it and have advanced 50 miles beyond it, building a traceable terminal moraine, and yet leave so much decayed rock even in exposed places, like hilltops and stoss slopes.

THE CAYUGA VALLEY

At Portland quarry, about 6 miles north of Ithaca on the east side of Cayuga Lake, the excavations for the removal of the Tully limestone have revealed a condition of profound decay. By this decay the upper layer of limestone has been separated into rounded blocks, with a reddish residual clay occupying the spaces between them, both along the vertical joint planes and along the nearly horizontal stratification plane between the two upper layers. The decay extends from 2 to 3 feet below the surface, and the residual clay is several inches thick. Delicate glacial striæ are still perfectly preserved on the surface of limestone blocks between and beneath which this residual clay occurs.

The depth and extent of this decay, together with the evidence of slight postglacial decay furnished by the glacial striæ, demonstrate that this residual clay was formed before the advance of the Wisconsin ice-sheet, and that in this place the erosion by the last ice-sheet was insufficient to remove the products of earlier decay. The site of this quarry, near the junction of Salmon Creek and Cayuga Lake on

a nearly level bench below the edge of the steepened slope of Cayuga valley, is a point where, if anywhere in the valley, glacial erosion should have been extensive.

Farther north, between Union Springs and Cayuga, marked decay was revealed in the gypsum beds of one of the quarries; but this has now been removed. It was situated on a level surface near the northern end of the Cayuga trough, at a point where glacial erosion should have been pronounced, and in a soft stratum which ice-erosion would easily wear away.

At frequent points near the heads of Cayuga and Seneca valleys, notably near Ithaca and Watkins below the edge of the steepened slope, there are pronounced cliffs, often several score yards in length and from 5 to 15 feet in height, with sharp edges and angles whose formation by ice-erosion is inconceivable. Their length and height, as well as the absence of rounded edges, indicate origin by weathering and not by ice-erosion; and that they were not produced after the ice disappeared is proved in a number of cases by the presence of till and moraine banked up against them and partly burying them.

A system of hanging valleys tributary to both the Cayuga and Seneca troughs ends at about the 900-foot contour, below which the valley slope is decidedly steepened. Down this steepened slope extend old gorges antedating the last ice-advance, and partly buried beneath deposits of the Wisconsin stage. So far as can be seen, the gorge walls are not markedly worn by ice-erosion. It has been proposed as a theory that the steepened slope and great depth of the Cayuga and Seneca valleys are the result of glacial erosion; but that such profound erosion, amounting to at least 845 feet in the Cayuga and 1,500 feet in the Seneca valley, could have been performed without erasing these earlier gorges, or at least so modifying them as to give evidence of such erosion, seems inconceivable.

The evidence in the Cayuga valley is believed to demonstrate that the work of erosion by the Wisconsin ice-sheet above present lake-level was very slight. What occurred below lake-level or during possible earlier ice-advances is not clear; but if this evidence eliminates erosion in the visible part of the valley by the only known ice-advance in this region, as it seems to do, it throws doubt upon the whole hypothesis of ice-erosion for this valley, notwithstanding the remark-

ably straight, smooth sides, the steepened slope, and the hanging valleys whose characteristics suggest ice-erosion origin.

CAPE ANN, MASSACHUSETTS

This cape, extending into the sea north of Boston, has upon it an interesting morainic deposit in which there are large numbers of bowlders (Fig. 2), in some cases with bands of bowlders piled one on the other, making bear-den moraines (Fig. 6). It is no overestimate to state that there are tens of thousands of bowlders on the Cape, and that fully 90 per cent. of these are of local origin, especially granite

FIG. 2.—Bowlders in the Cape Ann (Mass.) moraine, showing the ordinary condition of the moraine surface.

of which the Cape is chiefly made. So far no satisfactory explanation of this marked accumulation of local bowlders has been proposed.

Years ago I did work on the geology of Cape Ann as an assistant to Professor Shaler, and the result of his studies was published by the U. S. Geological Survey.[1] Numerous visits since then, together with the fact that quarrying operations have opened up scores of new exposures, have furnished new facts which show conclusively that ice-erosion on Cape Ann was very ineffective, and that the large numbers of bowlders are probably directly due to this fact. Indeed, they evidently represent the slightly moved bowlders of decay prepared for removal before the last ice-advance. The evidence of moderate ice-erosion is of several kinds, as follows.

[1] *Ninth Annual Report*, U. S. Geological Survey (1887–88), pp. 529–611.

Larger valleys.—In the first place, the major valleys all antedate the ice-advance, for they extend at all angles to the direction of ice-motion, and have all the characteristics of subaërially formed valleys.

Angular cliffs.—A second evidence is furnished by angular cliffs, especially on lee slopes. These vary in elevation from an inch or two to a score of feet or more, being due either to the influence of joints or of dikes. They are seen in all parts of the Cape, the smaller instances being revealed where quarrying operations have recently stripped rock-surfaces bare.

Some of the smaller cliffs may be the result of plucking, but the larger ones are certainly not of this origin. The smaller cliffs are often associated with incompletely developed *roches moutonnées* surfaces, which conform closely in outline to the concentric joints of the granite (Fig. 3). Viewed from the stoss side, these surfaces are typical *roches moutonnées*, but from the lee side they appear angular, with small cliffs extending from one *roches moutonnées* down to the next lower joint plane.

FIG. 3.—To show the relation of *roches moutonnées* surfaces and minor cliffs to the concentric jointing (dotted lines) of the Cape Ann granite.

Dikes.—In a number of places there are small valleys where dikes cross the granite, and these occur at all elevations, even above the level at which the sea formerly stood. They extend at all angles to the direction of ice-motion, and, being occupied by drift, are not of postglacial origin. Every evidence proves these valleys to be due to greater decay of the dike than of the inclosing granite; and that the ice should not have eroded the granite down to the level of this dike decay is proof of its slight erosive power at this point.

At the Rockport granite quarry one of these decayed dike valleys extends up to the edge of the quarry, and, while the residually decayed surface material is gone, there is evidence of some decay in the dike even to the bottom of the quarry. This decay consists of the develop-

ment of abundant joints in the dike and a slight disintegration along them. A similar case occurs where a large porphyritic diabase dike crosses a quarry at Pigeon Cove; but here residual clay remains along the joints, by which the dike is separated into a series of rounded bowlders.

"*Sap.*"—In all the quarries at Cape Ann the granite is stained yellow along both the vertical and horizontal joint planes. This stain, which in some cases extends three inches into the granite, is known by the quarrymen as "sap." It is due to a partial disintegration of the iron-bearing minerals and consequent staining of the granite. The depth to which this stain extends in the quarries, being found even at the very bottom of the largest, and the extent to which it enters the rock, are altogether too great for postglacial decay.

Joint planes.—Almost uniformly over the Cape it is the case that joint planes are much more numerous in the upper than in the lower portions of the quarries.[1] They are in some places so close together that small quarries have been opened and, after being worked for a while, have been abandoned because the "grout" (small irregular blocks stained with "sap" and useless even for making paving blocks), which must be handled and disposed of, is too abundant. These joint planes have evidently been developed by weathering, and by weathering of longer duration than postglacial times would permit. Glacial erosion has not been sufficient to remove this upper zone of jointed granite, although the joints produce masses favorable for plucking.

Interglacial (?) beds.[2]—At Stage Fort, just outside of Gloucester, there is a bed of fossil-bearing sands, clays, and gravels, overlain by till and grooved by glacial erosion. The layers are crumpled by the ice-shove. Although in the lee of a range of hills, it would hardly be expected that such a deposit would escape vigorous erosion.

Decayed granite.—In Lanesville, on the stoss slope of the Cape, and in a situation where there is no topographic reason for protection, there occurs in the Edwin Canney quarry a striking instance of decay in the granite (Figs. 4 and 5).[3] This decay, which extends

[1] See Plates LXVI and LXVII in *Ninth Annual Report*, U. S. Geological Survey, 1887–88.

[2] Tarr, *Bulletin of the Museum of Comparative Zoölogy*, Vol. XLII (1903), p. 189.

[3] See also Plate LI, *Ninth Annual Report*, U. S. Geological Survey, 1887–88.

along both the vertical and horizontal joint planes, has produced a gravel of disintegration to a depth of five feet and with a width, in one or two places, of eighteen inches. By it the granite has been separated into rounded, bowlder-like blocks incased in disintegrated granite gravel exactly like those revealed in quarries in Maryland where the granite is covered by a residual soil.

FIG. 4.—Disintegration of granite along joint planes at Lanesville, Cape Ann, Mass. Gravel underlies these bowlders, which are in place.

Nowhere on the Cape is so good an instance of decay found as this; but in dozens of places decayed gravel occurs along the joint planes, in one or two instances to a depth of five feet. These localities are found in all parts of the Cape, and on both stoss and lee slopes. In a number of places granite masses that are thus partly incased in gravel are scratched and polished on the surface, showing how slight has been postglacial decay, and proving that the disintegration farther down cannot be postglacial.

That these masses should have resisted ice-erosion is remarkable; and that this erosion has not extended below the level of the disintegrated granite is clear proof of its general weakness on Cape Ann.

The till.—One of the most striking features of the till of Cape Ann, aside from its bowldery nature, is its sandy and gravelly condition. In some cuts the till very closely resembles the disintegrated gravel above described, and everywhere it seems to contain a large percentage of this decayed material. From the field evidence I am convinced that the till of Cape Ann is in large part made up of gravel disintegrated before the last ice-advance and pushed forward a short distance to its present position.

The bowlders and bear-den moraines.—It has been stated above that the bowlders of Cape Ann are prevailingly local, probably as much as 90 per cent. being of rocks at present in place on the Cape. Many of these are angular (Fig. 2), with joint-plane faces, as if broken from a ledge and carried a short distance without attrition. On the other hand, many, although carried only a short distance, are well rounded.

Both of these conditions are readily explained on the theory that they represent the dislodged products of decay prior to the ice-advance. Fragments surrounded by disintegrated gravel were rounded; those broken from the markedly jointed sections had angular faces. No other explanation that has occurred to me will account for this vast number of local bowlders; and the fact that some unremoved masses are left (Fig. 4) points clearly to this explanation as the true one.

The bear-den moraines (Fig. 6), representing bands of excessive bowlder accumulations, occur at various levels, so that they can scarcely be assigned to marine action, on the assumption that when they were accumulated the sea stood at the ice-front. Opposed to this theory also is the further fact that some of the occurrences are on protected valley slopes where sea-action could not have been very effective. So far as observed, they are all situated on lee slopes, which suggests that they were combed over the edges of the hills by ice-push, and perhaps added to accumulations which, being in the lee, the ice was incapable of removing. The only alternative explanation that appears is that they owe their origin to the action of water run-

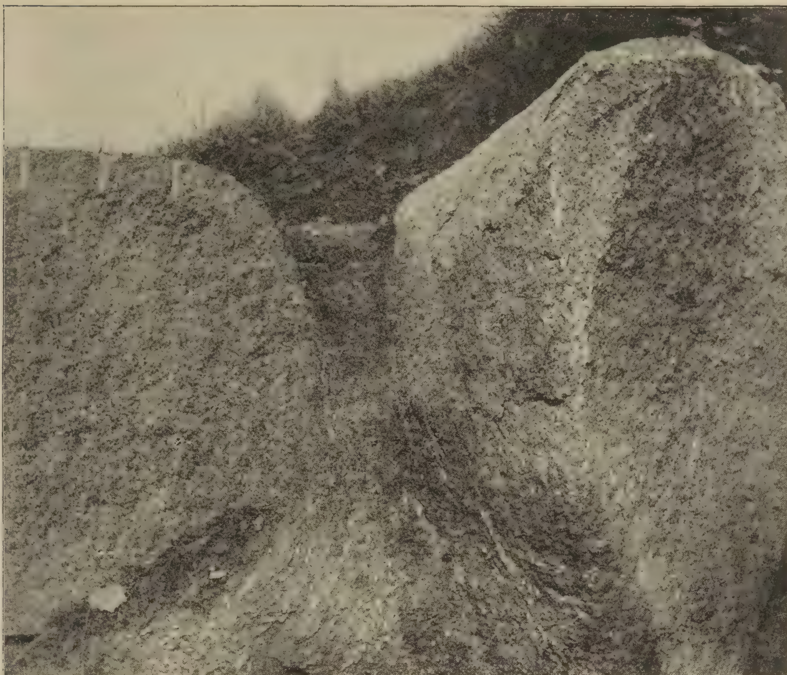

FIG. 5.— Disintegrated granite along joint plane at Lanesville, Cape Ann, Mass., showing a portion of Fig. 4.

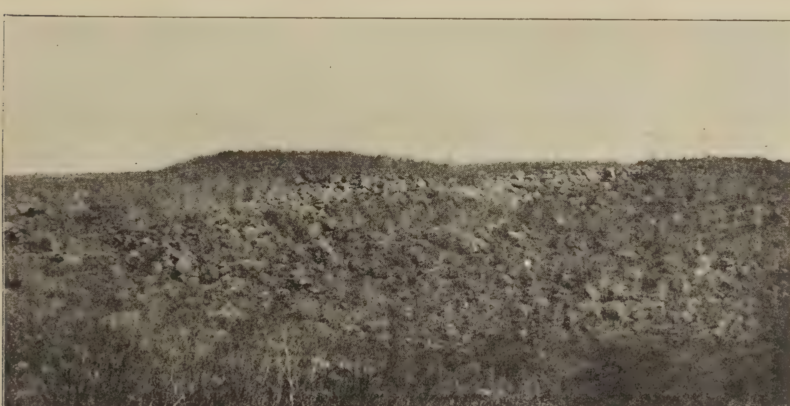

FIG. 6.— Bear-den moraine, on lee (southeast) slope of a granite hill, Cape Ann, Mass.

ning out from the ice-front, and, by removing the smaller fragments, concentrating the larger ones. Between these two theories I have been unable to find facts to decide.

Decayed bowlders.—Many of the bowlders have been broken open along joint planes since they were deposited by the ice. Although this is the result of postglacial weathering, it is due to the presence of joints partly developed before removal from the ledge. Other bowlders have disintegrated to gravel hills (Fig. 7) since they were

Fig. 7.—A granite bowlder in process of disintegration on Cape Ann, Mass. Other bowlders are represented only by heaps of gravel.

brought to their present position, and every gradation from slight disintegration to instances where only a mass of gravel remains to mark the site of a former bowlder, may be found by the score. This disintegration is surely postglacial; but, taken in connection with other facts indicating preglacial decay, it seems certain that such decay must have been made possible by the fact that, before removal from the parent ledge, the rock was already weakened by decay. Nowhere on the Cape is there such difference in the granite in place as to permit marked decay on one surface and slight decay on another, as is true among the bowlders. On the contrary, wherever the thin till-cover has been stripped from the bed-rock, its surface is found to be polished or scratched, proving that postglacial weathering has done little work.

Conclusion.—That glacial erosion failed to remove the products of preglacial decay on Cape Ann is evident from the facts stated above; and that the marked accumulation of bowlders on the Cape is due to this lack of erosive power is advanced as a theory toward which all facts point, while no facts at present known oppose it. Whether there are reasons why the ice was locally thus ineffective, or whether it is a common condition along the New England coast, I cannot say. The Cape is a moderate salient against which ice-currents may have divided, leaving this region only slightly affected by its erosive action. Facts from a wider area must be obtained to settle the question whether this condition is local or general along the New England coast.

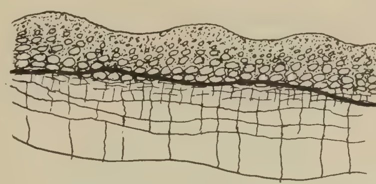

FIG. 8.—To illustrate the probable changes at Cape Ann. A jointed granite with joint planes increasing in number toward the surface, changing to a condition of bowlders with gravel between, and capped by residual soil, has, by ice erosion, been lowered to the level of the heavy line.

TURNAVIK ISLAND, LABRADOR

This island, which is approximately in latitude 55° N., is one of a number of islands in an indentation on the Labrador coast. It rises from 300 to 400 feet above the water and is a barren mass of rock, mainly porphyritic gneiss, so far as examined. Its surface is strongly glaciated, with numerous very perfect *roches moutonnées* forms, and many perfectly preserved striæ and deep grooves, but with very little till and few foreign bowlders.

Crossing the gneiss are a number of diabase dikes, one of which is 60 feet wide, and where these dikes occur their sites are quite uniformly indicated by chasms. The large 60-foot dike, whose site is marked by a long, deep valley (Fig. 9), extends at right angles to the direction of ice-motion, so that the valley cannot be explained by ice-erosion. That the chasm has not been formed since the ice left is proved by its rounded, ice-worn edges, and by the presence of fresh striæ on its walls. The valley is evidently the result of earlier decay; but that the ice removed the entirely disintegrated

products of this decay is proved by the fact that fresh diabase was collected in the bottom of the valley.

This dike chasm, produced before the last ice advance, was not entirely erased by glacial erosion, proving that at this point the ice did not accomplish much work. It would be interesting to know how widespread this weakness of ice-erosion was along the Labrador

FIG. 9.— Dike valley, formed before last ice advance, on Turnavik Island, Labrador.

coast, and whether this particular instance is due to some local retardation of the ice; but facts are not available for answer of these questions.

These observations, in widely scattered localities, do not prove anything beyond the regions in question. It is a well-known fact that the erosive power of ice varies with the conditions, and it is possible that close by some of these localities of moderate ice-erosion there may have been profound changes caused by the ice. Nevertheless, such pronounced cases of moderate ice-erosion, in such widely different situations, including surroundings apparently favorable to erosion, prove that under some conditions the erosive power of the

continental glacier was very limited. More facts are necessary before the exact efficiency of the ice as a sculpturing agent can be determined, or the reasons why it erodes little in one place and apparently a great deal in another. All that is claimed for this paper is that it is a small contribution toward the accumulation of facts necessary for these determinations.

Reviews

SUMMARIES OF RECENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE

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EDWARD B. MATHEWS. "The Structure of the Piedmont Plateau as Shown in Maryland." *American Journal of Science*, 4th Ser., Vol. XVII (1904), pp. 141–59.

Mathews discusses the structure of the Piedmont Plateau. The Baltimore gneiss (William's biotite gneiss in part) is correlated with the Fordham gneiss of New York, the Arrowmink arkosic gneiss of Philadelphia, the Carolina gneiss (in part) of the Washington area, all of which are referred to the pre-Cambrian. He concludes:

1. The older rocks of the Piedmont consist of both sedimentary and igneous types, which since their formation have been more or less metamorphosed.

2. The metamorphosed sediments include banded micaceous and hornblende gneisses of pre-Cambrian age; a more or less intermittent, thin-bedded, generally tourmaline-bearing quartzite of Cambrian age; an intermittent dolomitic marble or magnesian limestone of Cambro-Ordovician age; and a series of mica-schists and the gneisses of Ordovician age. Above these occur a somewhat intermittent, poorly developed quartzitic conglomerate and the Peach Bottom slates.

3. The igneous rocks consist of an immense gabbro sheet, intruded by numerous large bodies of granite and meta-rhyolite, and accompanied by numerous more basic serpentinized bodies. These various masses represent stages in a single extended period of igneous activity.

4. The time when this activity took place was later than early Silurian and earlier than the late Carboniferous; probably in the early part of this interval.

5. The chief structural features of the region are the metamorphism and constant schistosity, and the broader folding of the different rocks.

6. The metamorphism of the rocks, especially of the banded gneisses, probably commenced prior to the intrusion of the gabbro and granite, and was accentuated by them in the eastern portion of the Plateau.

7. The folding of the region is of the Appalachian type, the rocks occurring in several long, more or less parallel, folds, with few faults and but occasional overturned folds.

8. The eastern and western areas are probably of the same age; differences in metamorphism being due to the large bodies of deep-seated intrusives on the east and the smaller bodies of surface volcanics on the west.

9. The sequence found in Maryland may be recognized from Washington to Trenton and in the region north of New York.

A. A. JULIEN. "Genesis of the Amphibole Schists and Serpentines of Manhattan Island, New York." *Bulletin of the Geological Society of America*, Vol. XIV (1903), pp. 421–94.

Julien discusses the genesis of the amphibole schists and serpentines of Manhattan Island, New York (including the Manhattan and Fordham series), and concludes that they are derived from the alteration of basic igneous rocks. This appears established by the correspondence of the hornblende rock in chemical composition to basic igneous rocks and to hornblende schists of that derivation, by identity of its hornblende constituent with that found in volcanic rocks, by the discovery of many apophyses, isolated or in groups, and other structural features, and by the survival of products of contact alteration. The absence of pyroxene and of dike-like intersection of the associated gneisses may be well explained by the extent of shearing and metamorphism.

T. L. WATSON. "Granites of North Carolina." *Journal of Geology*, Vol. XII (1904), pp. 373–407.

Watson maps and petrographically describes the granites of North Carolina.

WILLIAM H. HOBBS. "The Geological Structure of the Southwestern New England Region." *American Journal of Science*, Vol. XV (1903), pp. 437–49.

"Lineaments of the Atlantic Border Region." *Bulletin of the Geological Society of America*, Vol. XV (1904), pp. 483–506.

Hobbs concludes that the crystalline rocks of southwestern New England have been deformed by a system of joints and faults of post-Newark age superimposed upon older structures which appear to be largely due to folding. He concludes further, that the crystalline and later rocks of the Atlantic coast in general show lineaments suggesting regular sets of faults in a nearly meridional series and in two other series which make nearly equal angles with this direction. Other lineaments which more closely approach the equatorial direction vary more from one another, and are both numerically less important and less strikingly brought out.

CHARLES R. VAN HISE. "A Treatise on Metamorphism." *Monograph No. 47*, U. S. Geological Survey, 1904. Pp. 1,286.

Van Hise discusses principles of metamorphism applicable to the study of pre-Cambrian and other metamorphic rocks, and cites many illustrative pre-Cambrian rocks and localities.

W. S. BAYLEY. "The Menominee Iron-Bearing District of Michigan." *Monograph No. 46*, U. S. Geological Survey, 1904. Pp. 513.

CHARLES R. VAN HISE AND W. S. BAYLEY. "The Menominee Special Folio." *Geologic Atlas of the United States*, Folio No. 62, U. S. Geological Survey, 1900.

Journal of Geology, Vol. IX (1901), pp. 451–54.

Bayley and Van Hise describe and map the geology of the Menominee iron-bearing district of Michigan. The essential facts are covered in a preliminary report summarized in a former number of this *Journal*. An additional feature of interest is the discovery of minute granules in the Menominee iron formation similar to the greenalite granules from which the Mesabi ores are largely derived.

Comment.—The age of the Quinnesec schists cannot be regarded as finally settled.

They have been assigned to the Archean because of lithological characteristics, but the contact between them and the Lower Huronian sediments to the north is covered by Upper Huronian and glacial deposits. Greenstones to the west on the Brulé River, similar to the Quinnesec schists, are closely infolded, and perhaps interbedded with slates which have been mapped as Upper Huronian. In view of these facts, it is quite possible that the Quinnesec schists are as late as Upper Huronian, thus corresponding to the Clarksburg volcanics of the Marquette district.

On the basis of the triple division of the Huronian series which has been adopted since the discovery of an unconformity in the previously called Lower Huronian series of the Marquette district, the Upper and Lower Huronian series are represented in the Menominee district, and not the Middle Huronian, unless we except certain pebbles taken to represent the Negaunee formation. It is still possible that the iron formation mapped as Upper Huronian may in reality be Middle Huronian, as suggested by partly hypothetical structural connection with formations mapped as Middle Huronian to the north, but in this case there should be found an unconformity between the iron formation and the slates above, and none has yet been found, although the field has been most carefully examined.

S. WEIDMAN. "The Baraboo Iron-Bearing District of Wisconsin." *Bulletin XIII*, Wisconsin Geological and Natural History Survey, 1904. Pp. 190, with map.

Weidman describes and maps the Baraboo quartzite region of south-central Wisconsin.

A pre-Cambrian quartzite formation, having an estimated thickness of 3,000–5,000 feet, forms an east-and-west synclinorium about 20 miles long, and ranging in width from 2 miles on the east to 10 or 12 miles on the west, resting on a basement of igneous rock consisting of granite, rhyolite, and diorite, in isolated and widely separated areas both north and south of the quartzite synclinorium. The largest area is one of rhyolite near the lower narrows of the Baraboo. The upturned north and south edges of the quartzite form respectively the North and South Ranges of the Baraboo Bluffs, standing 700–800 feet above the surrounding country and above the intervening valley. In the valley are pre-Cambrian formations younger than, and conformable with, the quartzite. These are the Seeley slate, having an estimated thickness of 500–800 feet, and above this the Freedom formation, mainly dolomite, having a thickness estimated to be at least 800 feet, bearing iron-ore deposits in its lower horizon.

Flat-lying Paleozoic sediments, unconformably overlying the pre-Cambrian rocks, occupy the surrounding area and partly fill the valley. The Paleozoic rocks range from Upper Cambrian, Potsdam, in the valley bottom to the Lower Silurian, Trenton, on the upper portions of the quartzite ranges. The Potsdam sandstone has a thickness ranging from a few feet to a maximum of about 570 feet in the valley. Glacial drift is abundant over the quartzite ranges and in the valley in the eastern half of the district, but occurs only in the valleys in the western half.

The iron ore is mainly a Bessemer hematite with soft and earthy, hard and black, and banded siliceous phases. A very small amount of hydrated hematite or limonite is also present. The rocks immediately associated with the ore and into which the ore grades are dolomite, cherty ferruginous dolomite, ferruginous chert, ferruginous

slate, and ferruginous dolomite slate—in fact, all possible graduations and mixtures of the minerals dolomite, hematite, quartz, and such argillaceous minerals as kaolin and chlorite. In the ferruginous rocks associated with the iron ore the iron occurs as hematite and also in the form of carbonate, isomorphous with carbonate of calcium, magnesium, and manganese in the form of ferro-dolomite and manganic-ferro-dolomite, and as silicates combined with various proportions of alumina, lime, magnesia, and manganese, as chlorite and mica, and also very probably to a small extent as iron phosphate.

It is believed that the iron ore of the Baraboo district was originally a deposit of ferric hydrate, or limonite, formed in comparatively stagnant, shallow water, under conditions similar to those existing where bog or lake ores are being formed today, and that through subsequent changes, long after the iron was deposited as limonite, while the formation was deeply buried below the surface and subjected to heat and pressure, the original limonite became to a large extent dehydrated and changed to hematite.

Comment.—The theory of the origin of the ores here proposed differs from that worked out for the Lake Superior region. It is believed that insufficient data are yet at hand to warrant a positive statement concerning the origin of the ores, and that until such data are at hand the theory worked out for the Lake Superior region in general, with which the Baraboo district has many points in common, should be assumed to apply to the Baraboo district. A detailed analysis and criticism of Dr. Weidman's argument is published by the reviewer in Vol. XXXV of the *Transactions of the American Institute of Mining Engineers.*

Drilling in the east-central portion of the valley has recently seemed to show the presence of an Upper Huronian quartzite series unconformably overlying the series described by Weidman, but this is yet to be confirmed.

JAMES M. BELL. "Economic Resources of Moose River Basin." *Report of the Ontario Bureau of Mines*, Part I (1904), pp. 135–97.

Bell describes the Laurentian and Huronian rocks of the Moose River basin. The former include acid igneous rocks, and the latter, greenstones, green schists, and certain sediments, with doubtful relations to each other and to the Laurentian.

GEORGE F. KAY. "The Abitibi Region." *Report of the Ontario Bureau of Mines*, Part I (1904), pp. 104–34.

Kay describes the rocks seen on a trip from Mattagami to Nighthawk and the area west of Lake Abitibi. No attempt is made to describe their stratigraphy and structure.

A. P. COLEMAN. "The Classification of the Archean." *Proceedings and Transactions of the Royal Society of Canada*, Vol. VIII (2d Ser., 1902), Sec. IV, pp. 135–48.

Coleman discusses the classification of the Archean (pre-Cambrian of the U. S. Geological Survey), and proposes the following:

Middle and Lower Cambrian ? or Algonkian ?	Keweenawan (Unconformity) Animikie

EPARCHEAN INTERVAL

- Archean
  - Laurentian = Fundamental gneiss, etc.
  - (Eruptive unconformity)
  - Huronian
    - Upper Huronian or Huronian proper
    - (Unconformity)
    - Lower Huronian or Keewatin
      - Schistose pyroclastics and eruptives
      - Coutchiching
    - = Grenvile and Hastings series

A. B. Willmott. "The Contact of the Archean and Post-Archean in the Region of the Great Lakes." *Journal of Geology*, Vol. XII (1904), pp. 40–42.

Willmott finds a step-like regularity in the contact of the Archean (pre-Cambrian of the U. S. Geological Survey) and the post-Archean rocks in the region of the Great Lakes, and believes it to be explained by a dislocation in the Archean before the deposition of the post-Archean sediments.

A. P. Coleman. "The Northern Nickel Range." *Report of the Ontario Bureau of Mines*, Part I (1904), pp. 192–224. With geological map.

Coleman describes and maps the northern nickel range of the Sudbury district of Ontario. It constitutes the northern upturned edge of a synclinal of eruptive rocks resting on Laurentian granites and gneisses, and including within it a little-disturbed basin of Cambrian or Upper Huronian sediments and tuffs. The contact with the rocks both above and below are eruptive. The eruptive grades from acid in its inner margin to basic in its outer or lower margin. The nickel is concentrated or upper in its basic edge.

A. P. Low. "Report on an Exploration of the East Coast of Hudson Bay." *Annual Report of the Geological Survey of Canada*, Vol. XIII (New Ser., 1900), Part D. With geological map.

Low describes and maps the geology of the east coast of Hudson Bay. With the exception of the rocks which form the chains of islands along shore between Portland promontory and Cape Jones, and also a narrow margin on part of the coast in the same region, they have all been cut by granite which has not only intimately penetrated them, but by its heat and pressure has so changed them to crystalline schists and gneisses that only in a few places can any trace of an original sedimentary origin be found. The unaltered sedimentary rocks with their associated sheets of trap and diabase bear a remarkably close resemblance not only to the so-called Cambrian rocks of other parts of the Labrador peninsula, but also to the iron-bearing rocks of the southern shores of Lake Superior and the Animikie and Nipigon rocks to the north of Lake Superior. In all likelihood they are of pre-Cambrian age and, in the opinion of the writer, are the oldest known sedimentary rocks of Canada. Notwithstanding this opinion, they will continue to be classed as Cambrian in order to correspond with the areas of similar rocks of Labrador which have already been so classed. The series comprises from the base up: Coarse arkose, banded arkose, sandstone and graywacke, chert, impregnated with oxide of iron and red jasper, cherty carbonate, carbonaceous shales, sandstone. Included in this series are sheets or laccolites of dark-green trap. This rock also flowed out to the surface. The basement rock from which this series is derived has not been recognized in the region under discussion.

J. E. Todd. "The Newly Discovered Rock at Sioux Falls, South Dakota." *American Geologist*, Vol. XXXIII (1904), pp. 35–39.

Todd reports the presence of gabbro within one-half mile of the Sioux quartzite, of South Dakota. He believes it to be intrusive into the quartzite, although no contacts are found.

E. R. Buckley and H. A. Buehler. "Quarrying Industry of Missouri." *Missouri Bureau of Geology and Mines*, Vol. II (2d Ser., 1904). With geological map.

Buckley and Buehler map and describe the pre-Cambrian granites of southeastern Missouri in connection with a report on the building-stones of the state.

J. D. Irving. "Economic Resources of the Northern Black Hills." Part I, "General Geology" by T. A. Jaggar, Jr., *Professional Paper No. 26*, U. S. Geological Survey, 1904, pp. 13–41. With geological map.

Jaggar describes the general geology of the Black Hills and gives particular attention to the dynamics of the later intrusions of the northern part of the uplift. The southern portion was occupied by massive ancient pegmatite granites, themselves pre-Cambrian intrusives in Algonkian strata. Probably they acted as a rigid cementing and hardening agent to prevent fracturing in the southern schists; the northern, less indurated phyllites cracked and faulted more readily to permit the younger intrusives to rise from the depths. The northern exposed schist areas contain many hundred dikes and some stocks; these must have induced movements of horizontal extension in the schist, and such movements are attested by bedding-plane faults at the base of the Cambrian. The dikes have a common trend and dip parallel with schistosity. The dip gave them tendency to spread in the Cambrian in one direction more readily than in another.

Two illustrative sections are given. North of the Homestake mine on Deadwood Creek, near Central, Algonkian rocks appear as follows from west to east: graphitic schist, mica-schist, heavy ferruginous black schist with quartzite bands cut by irregular white quartz bodies which form a distinct zone, ferruginous schist, mica-schist, all dipping toward the east; mica-schist with thin sandstone stringers, dipping to the west. This sudden change of dip just opposite the De Smit and Homestake ore bodies is significant, and suggests that perhaps the great ore body may fill a synclinal saddle pitching to the southeast.

A section from north-northwest to south-southeast along the ridge northeast of the Clover Leaf mine is: garnetiferous mica-schist, graphitic schist, ferruginous quartzite, amphibolite, mica-schist, white quartz, mica-schist, amphibolite, quartzite, and amphibolite.

Joseph A. Taff. "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma." *Professional Paper No. 31*, U. S. Geological Survey, 1904. With geological map. See also *Geologic Atlas of the United States*, Folio No. 98, U. S. Geological Survey, 1903.

Taff describes and maps the geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma. In the Arbuckle Mountains, unconformably below middle-Cambrian sediments, are granite, granite-porphyry, and aporhyolite containing basic dikes. The granite (Tishimingo) occurs in the eastern part of the mountains in

a rudely triangular area twenty miles in length and ten miles wide in its widest part, near the western end. The porphyry and aporhyolite areas occur in the Arbuckle Mountains proper in the western end of the uplift.

In the Wichita Mountains pre-Cambrian granite, granite-porphyry, and gabbro cut by diabase form a considerable part of the mountains. Granite is the principal mountain-making rock in the Wichita region. Its area is greater than that of all the other igneous rocks combined, and is about equal to that of the others and the older Paleozoic sediments. It makes all of the high land of the Wichita, Quana, Devil's Canyon, and Headquarters Mountains, and a large part of the Raggedy group.

The gabbro is exposed for the most part in the valleys or on the plains which surround the mountains. The granite porphyry comprises practically all of the Carlton Mountains, the igneous mass lying between the limestone hills in the vicinity of Blue Canyon, north of Mount Scott, and some hills near the northwest end of the limestone areas east of Rainy Mountain Mission.

Ernest Howe. "An Occurrence of Greenstone Schists in the San Juan Mountains, Colorado." *Journal of Geology*, Vol. XII (1904), pp. 501–9.

Howe describes green schists in the pre-Cambrian of the Needle Mountains in San Juan and La Plata Counties of southwestern Colorado. They comprise massive and schistose, granular and porphyritic meta-gabbro, and areas of mashed granitic intrusives and other schistose rocks, presumably altered quartzites. No evidence of surface origin is noted in the igneous rocks. The greenstones antedate the Algonkian sediments to the north, as shown by the pebbles contained in the Algonkian conglomerate, and have an older aspect than the other rocks of the neighboring areas. They are therefore assigned to the early Algonkian. Attention is called to their similarity to the greenstones of the Menominee and Marquette districts of Michigan and to rocks near Salida, Colo.

Arthur C. Spencer. "The Copper Deposits of the Encampment District, Wyoming." *Professional Paper No. 25*, U. S. Geological Survey, 1904.

Spencer discusses the geology of the Encampment district of Wyoming. Pre-Cambrian rocks form the main mass of the Sierra Madre Mountains with Mesozoic beds dipping away from them. They comprise sedimentary and igneous rocks. The sedimentary rocks are from the base up: hornblende schists, derived from surface volcanic rocks, interbedded with thin but persistent beds of sandy shale and impure limestone, limestone, quartzite, slate, and conglomerate. In the Encampment area the quartzite and slate formation is more in evidence than any other of the bedded rocks, but all occur in a limited area having the form of a narrow triangle, with its apex on the Encampment River about 5 miles south of Encampment, and its base, about 7 miles wide, in the foothills on the west side of the range. The belt of quartzites and associated strata is exposed for about 20 miles, but on the west their extent is not known, since they are overlapped by younger formations. The rocks within the sedimentary belt strike in general nearly east and west, and they seem at first sight to have an enormous thickness, since they dip almost invariably toward the south. An examination shows the sediments to be in an east-and-west synclinorium with axial planes of both major and minor folds dipping to the south. Strike faults and transverse faults are common.

A complex of igneous rocks comprising granite, quartz diorite, and gabbro, occur both to the north and south of the synclinorium, and the gabbro occurs also within the

synclinorium. The relations of the granite and quartz-diorite to the sediments are not definitely known, but their distribution is such as to suggest that they are intrusive into the hornblende schists at the base of the sedimentary series, and that with the hornblende schists they form the basement upon which the sedimentary rocks were deposited. The gabbro is intrusive into the sediments.

Comment.—The description indicates that the basal rock of this region, the hornblende schist, is similar in essential features to the schistose volcanic rocks with associated sediments making up the Keewatin series, the lowest in the Lake Superior region.

WALDEMAR LINDGREN. "A Geological Reconnaissance Across the Bitterroot Range and Clearwater Mountains in Montana and Idaho." *Professional Paper No. 27*, U. S. Geological Survey, 1904. With geological map.

Lindgren makes a geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho. Practically the entire area of the Bitterroot and Clearwater Mountains is occupied by granite with some gneiss. West of the Clearwater River, and only imperfectly exposed below the lava, is an extensive sedimentary area adjoining this granite; smaller sedimentary areas are exposed on Lolo Fork and on the head of the South Fork of Bitterroot River. In no place have well-defined fossils been found, but there is some foundation for the belief that the two last-named areas on the east side are very old, possibly pre-Cambrian, while the western area probably includes Triassic, Carboniferous, and possibly still older sediments. The granite constitutes a great bathylith whose age is not certain, but probably of post-Triassic age. The gneisses include older gneisses of the Clearwater Mountains, probably of pre-Cambrian age, and later gneisses resulting from the deformation of the granite occurring principally on the eastern side of the Bitterroot Mountains. On the accompanying map all are colored together as pre-Tertiary.

F. L. RANSOME. "The Geology and Ore Deposits of the Bisbee Quadrangle" *Professional Paper No. 21*, U. S. Geological Survey, 1904. "Geology of the Globe Copper District, Arizona." *Professional Paper No. 12*, U. S. Geological Survey, 1903. "Description of the Globe Quadrangle." *Geologic Atlas of the United States*, Folio No. 111, 1904. "Description of the Bisbee Quadrangle." *Geologic Atlas of the United States*, Folio No. 112, 1904.

Ransome describes in the Pinal Mountains of the Globe district of Arizona mica-schists with occasional bands of amphibole-schists which he calls the Pinal schists. These are intruded by quartz, mica-diorite, and granite. The schists and intrusives are unconformably below a non-fossiliferous series supposedly of pre-Cambrian age. The schists are believed to represent metamorphosed arkoses or grits. They are probably to be correlated with the Vishnu series of the Grand Canyon, provisionally called Algonkian by Walcott. In the absence of other criteria the Pinal schists are referred to the pre-Cambrian.

In the Mule Mountains of the Bisbee district, 90 miles to the south, are similar schists, also called Pinal schists.[1] Evidence of sedimentary origin is less satisfactory then in the Globe district and pre-Cambrian granitic intrusives are absent. Here also they are referred to the pre-Cambrian.

[1] The Pinal schists probably correspond to the Arizonian schists of Blake, *Engineering and Mining Journal*, Vol. XXXV (1883), pp. 238, 239.

A Geological Reconnaissance Across the Bitterroot Range and Clearwater Mountains in Montana and Idaho. By WALDEMAR LINDGREN. (Professional Paper No. 27, U. S. Geological Survey, 1904.) Pp. 122, XV plates, and 8 figures.

The area embraced in Mr. Lindgren's reconnaissance contains about 12,000 square miles, of which 6,000 are included in the Bitterroot Forest Reserve. It lies between the 113th and 117th meridians and between the parallels of 45° and 47°. Roughly speaking, one-fifth of the area is in western Montana, and the remainder extends across Idaho to the Washington boundary. The whole area lies in the watershed of the Columbia River. The Snake River is the largest stream which has its source in the region.

From east to west the characteristic topographic features are, in order, the following: (1) the Bitterroot Valley, (2) the Bitterroot Range, attaining an elevation of some 11,000 feet, and merging westward into (3) the great, dissected, high plateau of the Clearwater Mountains, and still farther westward (4) the Columbia River lava plateau, to which the Clearwater plateau descends rather abruptly. In this great plateau such streams as the Salmon, Clearwater, and Snake are deeply incised.

The geology is fairly simple, according to Mr. Lindgren's statement. The main Bitterroot Range is a quartz-monzonite mass, the northward continuation of the central Idaho bathylith. This is an intrusive mass of probably post-Carboniferous age.

The eastern slope of the range is a fault plane that dips about 18° to the east. The rocks of the fault zone are both gneissic and schistose. In addition to these igneous and metamorphic rocks, there are areas of sedimentaries, quartzites, and slates, supposed to be of Cambrian or pre-Cambrian age. Into this series the granite is found to have quite extensively intruded. Other areas of sedimentaries, supposed extensions of the Seven Devils' series, are presumably Mesozoic. The granite of the Clearwater Mountains is intrusive into these in many places. These sedimentaries are confined, as a rule, to the flanks of the central granite mass, which is the prevailing rock in both the Bitterroot and Clearwater Mountains.

The Columbia River plateau is formed of essentially horizontal lava flows, in which are intercalated shallow water deposits which contain Miocene plant remains. In the discussion of the lava flows, Mr. Lindgren mentions some interesting facts that go to show the existence of differential uplifts and subsidence in the plateau region.

Glaciation, whose effects are to be seen down to about 4,000 feet in some places, is also given some considerable mention. This must have been one of the most extensively glaciated regions in the whole Cordilleran system

From an economic standpoint this district has not yet proved a dangerous rival of its sister regions farther north in the Cœur d'Alène Mountains. The valuable minerals are chiefly confined to the western slope of the Clearwater Mountains. Gold, in fissure veins and gravels, is the most important mineral. Some few prospects of copper, silver, and silver-lead ores have been worked. Elk City is the chief center of the mining industry of the region.

Some fair coal of a lignitic character, and of probably Tertiary age, has been discovered, but may not prove profitable on account of the thinness of the beds. This lignite is found in two rather remarkable associations. In one case the lignite is interbedded with rhyolitic flows, and in the other in a series of sediments intercalated in the Columbia River basaltic flows.

It is evident that this region, because of its great extent and rugged character could merely be skimmed over in a reconnaissance, and, doubtless, much of interest yet awaits the scientist and practical miner.

W. D. S.

"A New Marine Reptile from The Trias of California," *University of California Publications*, Vol. III, (1904), pp. 419–21.

Among the recent discoveries in vertebrate paleontology, none is of greater interest than that by Dr. Merriam of a new order of marine reptiles to which he has given the name Thalattosauria, from the typical genus *Thalattosaurus* Merriam, from the Upper Trias of California. This new order presents many of the peculiar aquatic adaptations of other well-known, marine saurians, though differing markedly in structure. The skull is elongate; the vomers (prevomers) and pterygoids are covered with flat, button-like teeth, primitive characters lost in all other marine reptiles, save the pterygoid teeth of the mosasaurs; the dorsal ribs are single-headed; and the bones of the limbs are short, though the pelvis is robust, indicating, either incomplete aquatic adaptation, or a short non-propelling tail. The order is related, the author thinks, more to the early rhynchocephaloid reptiles than to the ichthyosaurs. Further information concerning these strange reptiles will be awaited with interest.

S. W. W.

"Neue Zeuglodonten aus dem unteren Mitteleocen vom Mokattam bei Cairo," *Geologisch-Paläontologische Abhandlungen*, Vol. VI (1904), p. 199.

A startling suggestion as to the origin of the Zeuglodon "whales" is that given by Professor Fraas in a recent paper on the Zeuglodonts from

the Eocene of Africa: "Systematisch betrachtet trenne ich die Archaeoceti vollständig von den Cetaceen und schliesse sie als Untergruppe an die Creodontier an, während die übrigen Walthiere nach wie vor eine selbständige Gruppe bilden, die so lange beliebig in der Systematik eingeschaltet werden kann, bis wir deren Stammesgeschichte kennen;" and his conclusion that these animals belong among the early carnivora seems well substantiated by him.

S. W. W.

"*Teleorrhinus browni*—a New Teleosaur in the Fort Benton," *Bulletin of the American Museum of Natural History*, Vol. XX (1904), p. 239.

Another discovery of much interest is that of a true teleosaur crocodile from the Benton Cretaceous, by Professor Osborn. That the teleosaurs should occur in America is perhaps not so remarkable as their occurrence in the Upper Cretaceous, all the forms hitherto known being from the Jurassic and Wealden of Europe. The specimen upon which Professor Osborn bases his new genus *Teleorrhinus* has a skull one meter in length, and typical teleosaurian vetebræ, the latest biconcave crocodile vertebræ known.

S. W. W.